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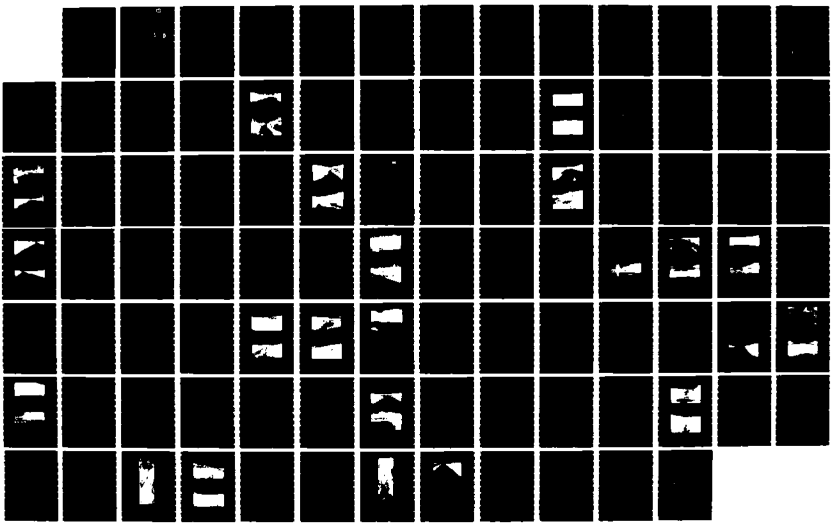

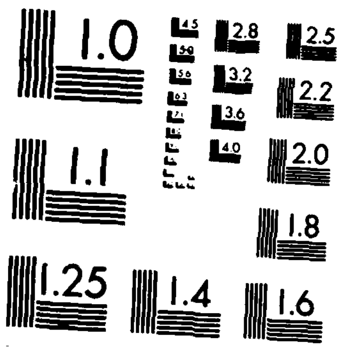

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Special Report 86-28

September 1986

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

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Engineering surveys along the Trans-Alaska Pipeline

Randy N. Godfrey and Robert A. Eaton

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, *published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

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During the spring of 1976, environmental engineering investigations along the Alyeska Pipeline Haul Road and TAPS (Trans-Alaska Pipeline System) Road were initiated by CRREL in conjunction with the Federal Highway Administration and the Alaska Department of Highways. The three-year research project had two general objectives: 1) to systematically obtain data on selected highway, airfield and pipeline workpad test sites and adjacent terrain to establish the rates and types of modifications in permafrost-dominated regions, and 2) to provide the basis for improved design criteria and specifications governing road, airfield and workpad construction and restoration in permafrost zones that are influenced

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20. Abstract (cont'd)

by many different seasonal climatic regimes. This report presents the results of 14 test areas not covered in CRREL Report 80-19, "Environmental Engineering and Ecological Baseline Investigations along the Yukon River–Prudhoe Bay Haul Road" (Brown and Berg 1980). The data presented here will be utilized for improving road, workpad and airfield design and construction, and for developing methods of minimizing the impacts on the environment in Alaska. The results show that thaw depths adjacent to the test sites increased each year from 1976 to 1978, causing continued settlement along the embankments. The depths of thaw beneath the gravel surface road and the air thawing index decreased from south to north. Thaw subsidence of the road sideslopes has caused the trafficked surface to become narrower as the sideslopes become wider and flatter. Since the rate of permafrost degradation and resulting thaw settlement has decreased annually, the thermal regime appears to be stabilizing. When the gravel workpads, roadways and runways are graded, any edge berms that would inhibit lateral runoff of water must be removed. Runoff water that ponds on the tundra adjacent to the roadway or workpad or airfield embankments should be avoided to eliminate subsidence caused by heat absorption.

PREFACE

This report was prepared by Randy N. Godfrey, Civil Engineering Technician, and Robert A. Eaton, Research Civil Engineer, both of the Geotechnical Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

All investigations were accomplished under the Expedient and Permanent Roads and Airfields Project as part of the CRREL Alaska Pipeline Program, DA Project 4A762730AT42, Design, Construction and Operations Technology for Cold Regions, Technical Area D, Cold Regions Design and Construction, Work Unit 004, Volume Changes Induced by Freezing and Thawing of Pavement Systems.

The authors thank David A. Gaskin and Dr. Richard L. Berg of CRREL for their technical review of this report. Special appreciation goes to the Alyeska Pipeline Service Company and the Bureau of Land Management, which allowed access to the road and study sites; Catalino Espiritu, who assisted in the reduction of road surveys and temperature data; and James Morse, Blanchard Pratt, Richard Guyer and Kenneth Straney, who assisted in fabricating the temperature sensors. Harold Larsen prepared the numerous engineering drawings, and Eleanor Huke prepared many of the maps. Robert C. Lindsay of CRREL and Michael Snelling, a Hanover High School work-study student, assisted in the final report preparations. All other CRREL personnel who helped in any way with this project are sincerely thanked.

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ENGINEERING SURVEYS ALONG THE TRANS-ALASKA PIPELINE

by

Randy N. Godfrey and Robert A. Eaton

INTRODUCTION

This report describes 14 test areas selected for studying environmental engineering problems associated with roadways, airfields and workpads along the trans-Alaska pipeline. It supplements "Environmental Engineering and Ecological Baseline Investigations along the Yukon River-Prudhoe Bay Haul Road" (Brown and Berg 1980). These sites were selected for investigating physical changes resulting from road, airfield and workpad construction and restoration in subarctic, discontinuous permafrost zones and in arctic, continuous permafrost zones, both of which are influenced by many seasonal and annual climatic regimes.

All selected sites were surveyed near the end of the 1976, 1977 and 1978 thawing seasons to determine changes in surface elevation.* Thaw depths adjacent to the roads, airfields and workpads were measured each year by probing with a metal rod. In 1977, soil strength was tested at most sites using a cone penetrometer, and at some sites solar radiation was measured. The purpose of these measurements was to establish rates and types of modifications in permafrost; these data should help in selecting future routes.

Table 1 is a list of the 14 sites along with some identifying characteristics. Four airfields were chosen north of the Yukon River for monitoring annual movement of the north and south ends of the runway surface. Two access road sites and one above-ground pipeline workpad site were also selected north of the Yukon River where problems were observed or anticipated. Test sections were selected at miles 16.3 and 50.7 on the TAPS (Trans-Alaskan Pipeline System) Road (now designated as the Dalton Highway by the Alaska Department of Highways), which extends 56 miles south from the Yukon River to Livengood. Also included in this study are five pipeline workpad test sites south of the Yukon River.

Figure 1 shows the locations of the test sites. The physiographic units traversed by the Haul Road, TAPS Road and oil pipeline are shown in

* Two sites, Hogan Hill and Eielson, were not surveyed in 1976.

Table 1. Test sites.

Site	Location	Latitude-longitude	Approximate elevation (m)	General soil type	Description
Willow Creek	Mile 98.8 Richardson Highway	61°50'N 145°26'W	904	Lacustrine deposits	Above-ground pipeline workpad
Hogan Hill	Mile 155.1 Richardson Highway	62°40'N 145°25'W	675	Lacustrine deposits	Buried refrigerated pipeline workpad
Quartz Lake	Mile 277.85 Richardson Highway; 0.75 miles north of Quartz Lake road	64°14'N 145°36'W	229	Perennially frozen silt, undifferentiated	Above-ground pipeline workpad
Eielson A.F.B.	1.5 miles north of Quarry Road along pipeline	64°38'N 146°35'W	152	Loess	Buried pipeline workpad
Engineer Creek	Approx. 1.5 miles south of Steese Hwy.-pipeline intersection	65°05'N 147°10'W	276	Perennially frozen silt, undifferentiated	Above-ground pipeline workpad
TAPS Road Mile 16.3 (CRREL Site #73-1)	Mile 16.3, Trans-Alaska Pipeline Service Road	65°30'N 149°22'W	494	Windblown silt	Roadway
TAPS Road Mile 50.7 (CRREL Site #78-1)	Mile 50.7, Trans-Alaska Pipeline Service Road	65°49'N 149°31'W	358	Extrusive, intrusive and sedimentary	Roadway
Old Man Airfield (CRREL Site #87-1E, 87-1W)	Approx. 50 miles north of Yukon River	66°27'N 150°35'W	396	Colluvium	East and west ends of runway
Prospect Airfield (CRREL Site #91-1N, 91-1S)	81 miles north of Yukon River	66°49'N 150°39'W	337	Mafic locally contains schist	North and south ends of runway
Dietrich Airfield (CRREL Site #104-1N, 104-1S)	Approx. 153 miles north of Yukon River	67°44'N 149°45'W	450	Modern alluvium	North and south ends of runway
Galbraith Lake Airfield (CRREL Site #114-1N, 114-1S)	Approx. 207 miles north of Yukon River	68°29'N 149°29'W	823	Cretaceous and Jurassic shale, sandstone and conglomerate	North and south ends of runway
Access Road 114-APL-3 (CRREL Site #114-APL-3)	207 miles north of Yukon of Yukon River, station 1375+98 on Haul Road	68°27'N 149°22'W	818	Alluvial fans	Access road
Insulated workpad, (CRREL Site #121-1)	250 miles north of Yukon River, pipeline station 1193+33	68°56'N 148°53'W	437	Young alluvial terraces	Above-ground pipeline workpad
Access Road 133-APL-1 (CRREL Site #132-2)	327 miles north of Yukon River, Haul Road Station 1838+04	69°51'N 148°46'W	80	Old alluvial terraces	Access Road

Note: CRREL Site numbers - the first 2 or 3 digits refer to Alyeska Alignment Sheets and the remaining numbers and letter, preceded by a hyphen, refer to the site on a particular alignment sheet. Site numbers on an alignment sheet are numbered from south to north.

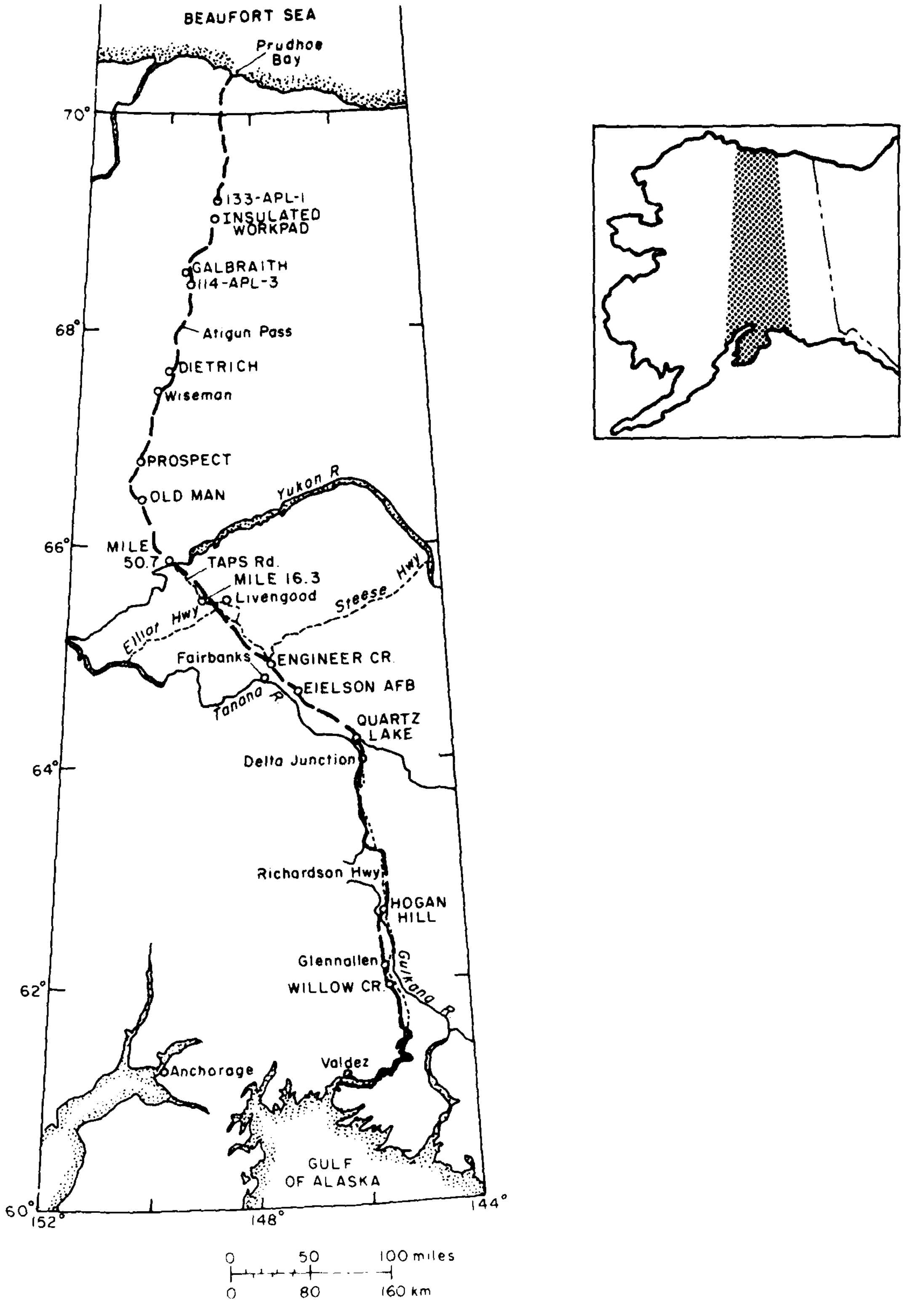


Figure 1. Location of the Haul Road, pipeline workpads, and airfield test sites.

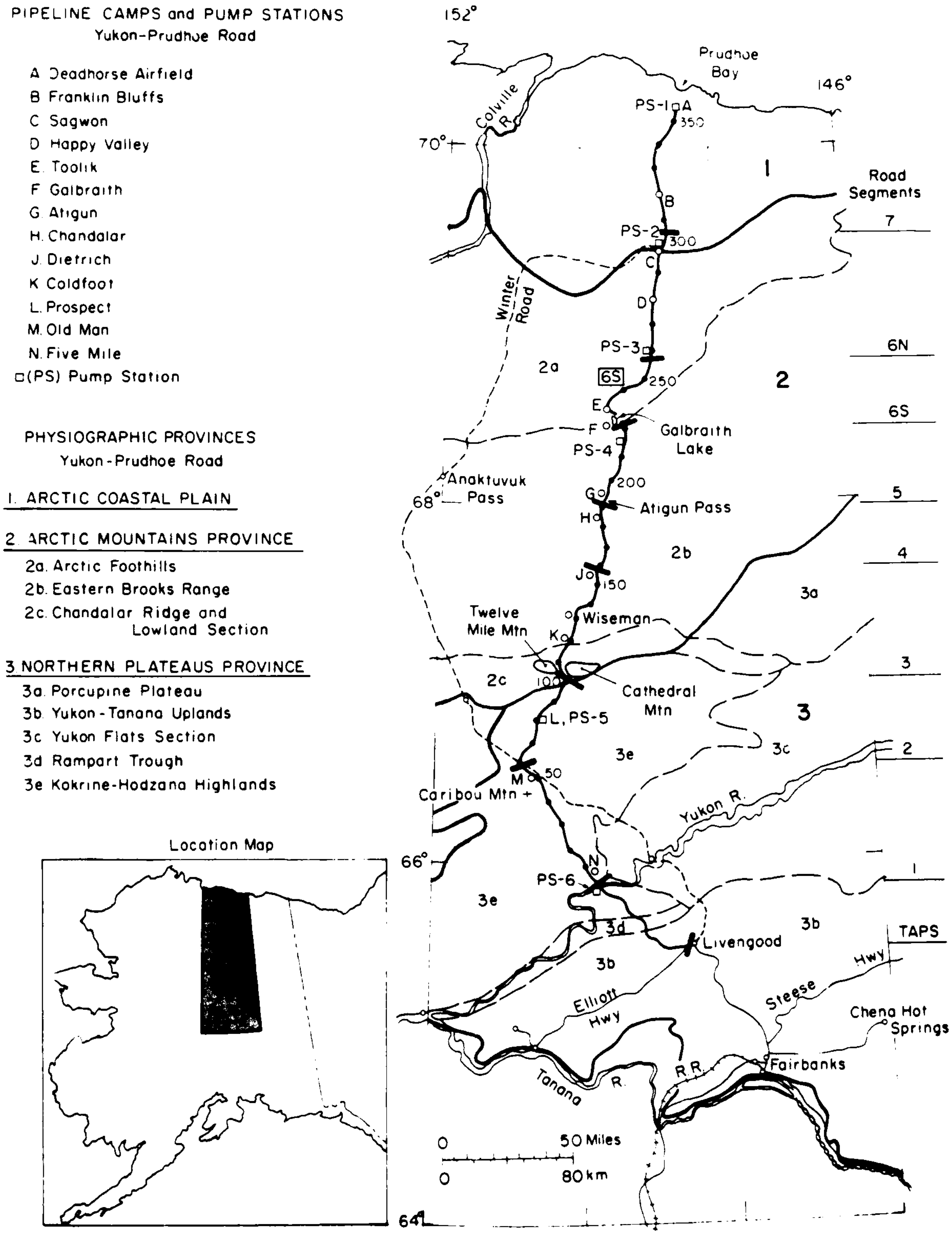


Figure 2. Location of the Haul Road showing the physiographic units traversed.

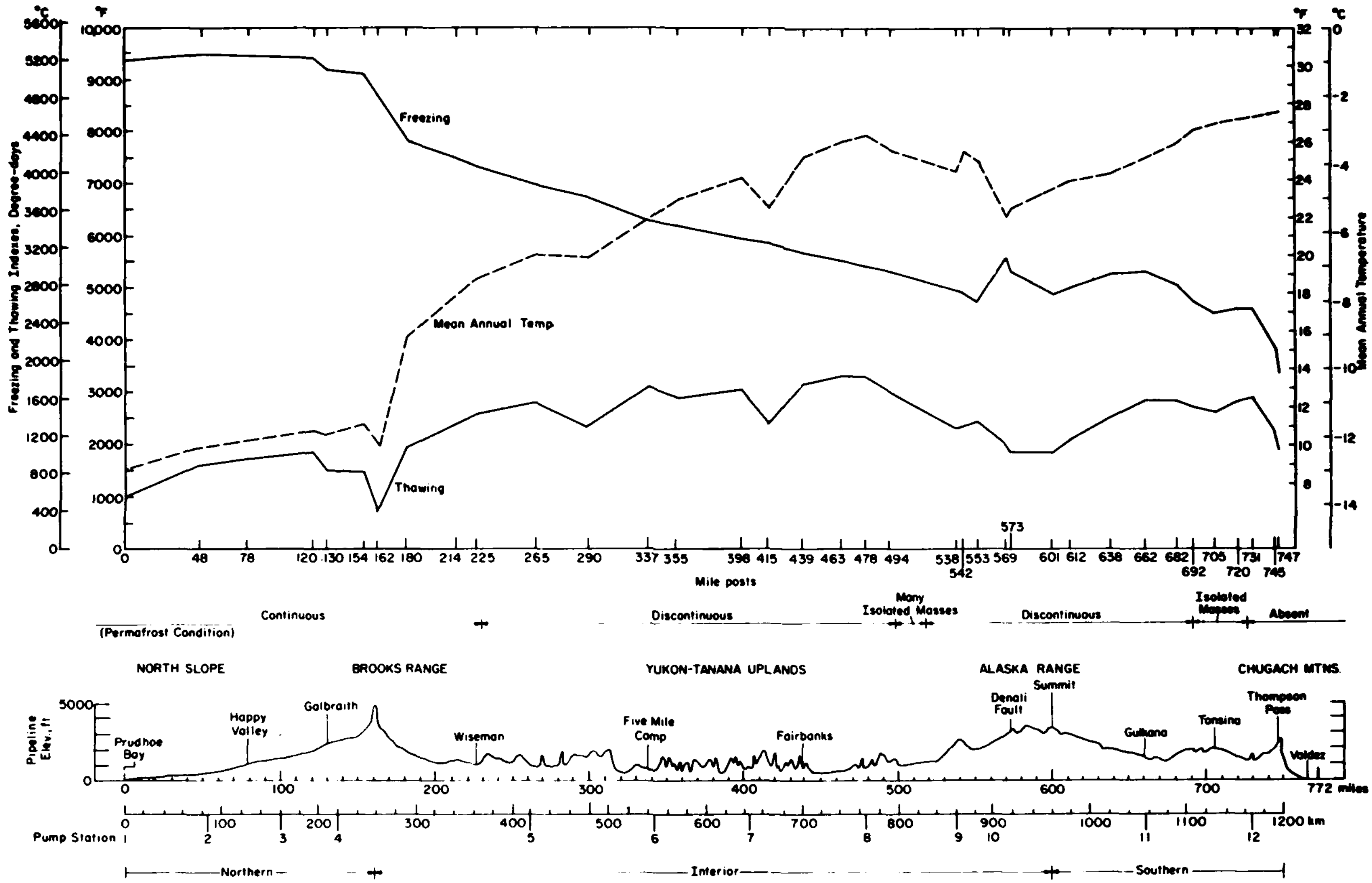


Figure 3. Distribution of freezing and thawing degree-days and mean annual temperature as a function of pipeline and highway elevations, latitude and longitude between Prudhoe Bay and Valdez. (Compiled and analyzed by R. Haugen, CRREL.)

Figure 2. Figure 3 illustrates the range in freezing and thawing conditions encountered along the pipeline route. Photographs of each location are included in each site description.

The test sites offer a good comparison of roadway, airfield and workpad behavior in a discontinuous permafrost zone and a continuous permafrost zone, where there are many areas containing massive ground ice. Thawing of the massive ice adjacent to or under these construction systems and the subsequent subsidence or erosion are of major concern, as they will affect performance and maintenance of the roadway and workpads. Test sites where the oil pipeline was constructed above ground adjacent to the roadway were chosen because the ice-rich soils there, if thawed by the road, provide a low bearing capacity.

METHODS

At all test sites, information on the thickness of the roadbed, the material sources, the solar radiation, and the depth of the permafrost were needed for evaluating both short- and long-term performance of the roads, airfields and workpads. These data will be used for improving road, workpad and airfield design and construction and for developing methods of minimizing influences on the environment. Monitoring incident solar radiation and material types provided significant data for correlating with the variation of thaw penetration in undisturbed areas.

Thaw penetration and transverse and longitudinal elevations were monitored at three of the four above-ground pipeline workpad sites (Willow Creek, Quartz Lake and Engineer Creek) and at both buried pipeline workpad sites (Hogan Hill and Eielson A.F.B.).

Four types of measurements were made during this study:

1) Level Surveys - to monitor surface elevation.

2) Probings- to determine the depth of thaw.

3) Cone penetrometer tests - to determine soil strength.

4) Solar radiometer readings - to determine incident and reflected solar radiation of different ground surfaces.

Level Surveys

Engineer level surveys were conducted each year at each test site. Transects were established across the roads, airfields and workpads into

adjacent disturbed and undisturbed areas. The surface elevations obtained in 1977 and 1978 were compared at most sites, with the initial elevations recorded in 1976.

Frost-free benchmarks (BM) were required for reference; National Geodetic Survey (NGS) benchmarks were used where available. Because of winter frost action, a few vertical control monuments were thought to have frost-heaved. To correlate yearly level observations, elevations of these disturbed monuments were mathematically adjusted, which produced satisfactory results. Most temporary benchmark (TBM) descriptions were without an elevation, so 30.48 m (100.00 ft) was arbitrarily selected as a datum. Descriptions and locations of all referenced benchmarks are included with observations for each test site.

Cone Penetrometer Tests

A cone penetrometer with a shaft slightly over 46 cm long and a cone 1.3 cm in diameter was used for all tests. Between the handle and shaft is a proving ring with a dial gauge that gives the results of the test in pounds per square inch (psi).

Cone penetrometer tests were performed in late August and September 1977 at 12 sites and in late August 1978 at Eielson A.F.B. to correlate with other data used in the design of embankment thicknesses. A cone penetrometer reading of approximately 80 psi corresponds to a California Bearing Ratio (CBR) value of 3. Unfrozen soils having a CBR greater than 3 correspond to competent subgrades. These subgrades have higher densities and lower moisture contents than ice-rich soils and will not consolidate as much under a fill placed over them. Standard, temperate-zone procedures may be used for designing required embankment thicknesses over competent subgrades. Over incompetent subgrades (soils with a CBR of less than 3 after thaw), embankment thickness design is based on the "reduced subgrade strength" method.

Incompetent subgrade soils were encountered along more than 60% of the Haul Road, which extends from the Yukon River to Prudhoe Bay, indicating that high ice content predominated (Berg and Brown 1978). These soils are considered to have low bearing capacity when thawed.

Thaw Probings

The depth of thaw adjacent to most test sites was measured each summer at most sites by probing with a thin metal rod (approximately 1.3 cm in diameter).

Solar Radiometer Readings

Incident and reflected solar radiation measurements were made with a standard solar radiometer at four sites in 1977 and one in 1978. The value for albedo was computed by dividing the reflected radiation by the incident radiation. These data were obtained for correlation with similar values observed at sites on the Haul Road; any detailed analyses of the data will be reported elsewhere.

RESULTS

Willow Creek

Figure 4 shows the location of this test site. It is an above-ground pipeline workpad (Fig. 5), varying in thickness from about 0.5 to 0.9 m. The closest identifier is a buried game crossing just south of the test

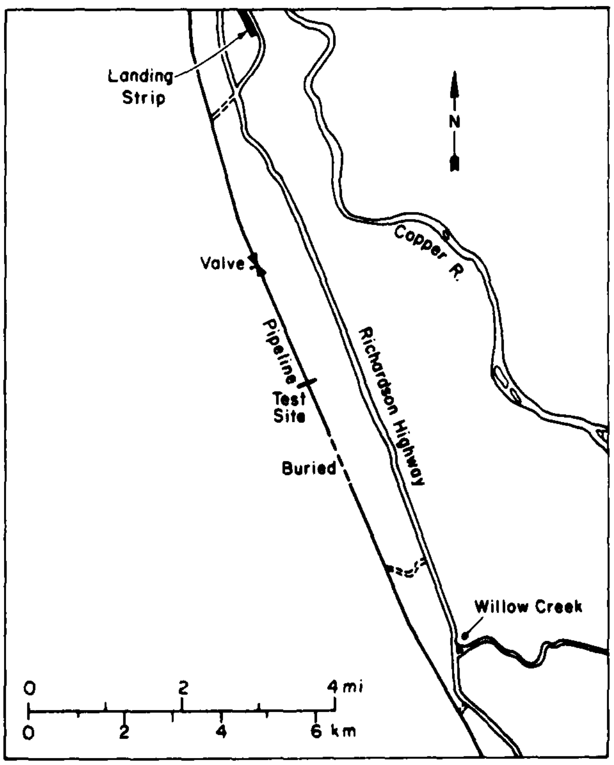


Figure 4. Willow Creek test site location.

a. Looking north along the east side of the workpad from the centerline at VSM #49. Note the stones left on the surface after grading.

b. Looking north along the west shoulder of the workpad from VSM #49. Note the wood planking used to support the horizontal strut of the VSM.

Figure 5. Willow Creek site, September, 1977.

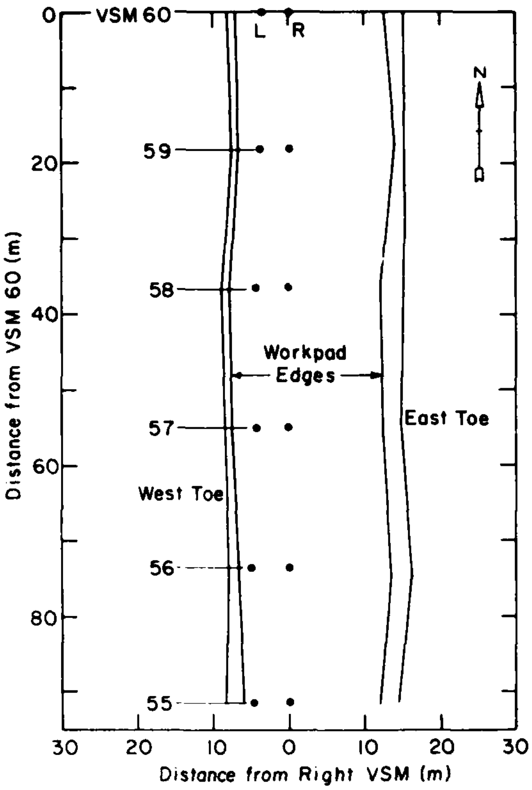


Figure 6. Plan view of the Willow Creek site.

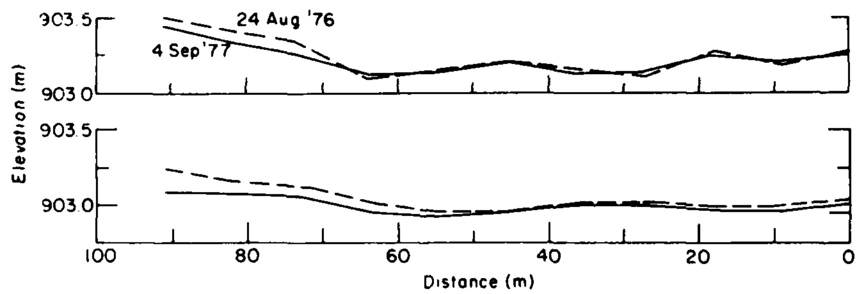


Figure 7. Willow Creek workpad longitudinal profiles. The upper profile is at the right VSM; the lower profile is 10 m east of the right VSM.

site. Figure 6 is a plan view of the test site indicating the locations of vertical support members (VSMs), workpad edges and toes of slopes.

An Alyeska Pipeline Service Company (APSC) benchmark (BM) located on a straight line west of VSM 49, with a known elevation of 903.329 m, was used to establish a temporary benchmark (TBM). The APSC BM is 9.90 km from the centerline of Kluth's River, 7.00 km from Route 4, 6.28 km from the Access Road and 2.90 km from valve 5 at Station 3051 + 927. The TBM is a vertical spike in a tree root on the west side of the road between VSM 55 and 56, and is approximately 0.49 m above ground.

The surface elevations were measured on 24 August 1976, 4 September 1977 and 18 August 1978. Figure 7 shows elevations along the longitudinal workpad profiles for 1976 and 1977, and Figure 8 shows the elevations on typical cross sections, also for 1976 and 1977. Surface elevations for 1977 and 1978 were essentially the same. The difference in elevation between the 1976 and 1977 surveys can be attributed to regrading of the workpad.

Table 2 shows the cone penetrometer measurements made on 4 September 1977. Observations were made at depths of 0, 15, 30 and 46 cm adjacent to the VSMs. The points on the east side of the VSMs had the higher values and were thus considered to have the greater soil strength. All depths greater than 1.0 m were too dense to probe, so no probe observations were taken at this test site.

Solar radiometer readings performed 4 September 1977 on the workpad surface show 170 Btu/ft^2-min. for incident solar radiation and 40 Btu/ft^2-min. for reflected solar radiation, giving an albedo of 0.24. These values indicate that most of the solar radiation received is absorbed by the workpad gravel surface, penetrating the subgrade and increasing the depth of thaw.

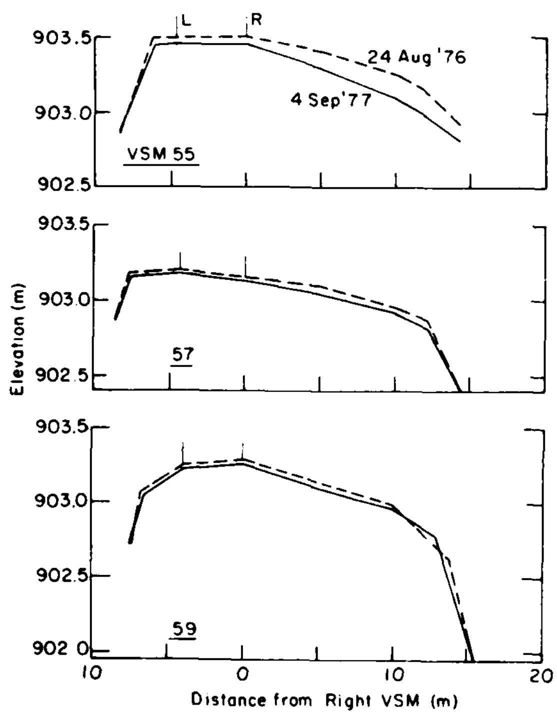


Figure 8. Willow Creek workpad, typical cross sections, 1976 vs 1977.

Table 2. Cone penetrometer measurements at Willow Creek (4 September 1977).

VSM No.	Dist. from Rt.VSM (m)	Soil strength (psi) 0	15	30	46 cm
55L	10.0W	0	100	130	60
55R	15.3E	20	160	190	220
56L	9.5W	10	50	160	150
56R	17.5E	60	100	220	280
57L	9.6W	30	260	260	40
57R	15.7E	40	280	>300	---
58L	9.9W	20	150	180	120
58R	15.9E	10	240	>300	---
59L	8.6W	50	220	260	290
59R	16.3E	20	270	>300	---
60L	9.2W	50	120	180	260
60R	15.9E	10	230	240	250
Average:		27	192	>227	186

Hogan Hill

Figures 9 and 10 show this buried, refrigerated pipeline test site and the surrounding vicinity. Figure 11 is a plan view of the site. An existing benchmark was used for the 1977 and 1978 surveys at this site. The benchmark is numbered 27-16-74 and is the top of a nail in a spruce tree 10.2 cm in diameter, 22 m east of a telephone pole on the east side of the pipeline. It projects 52 cm above the ground surface and has an elevation of 674.57 m.

Table 3 lists the average difference in elevations between 1977 and 1978. A centerline profile level survey was not conducted because of time limitations. Figure 12 shows details of the standard design for a buried, refrigerated pipeline segment and a cross section typical for the site.

Table 4 shows the cone penetrometer measurements for this pipeline section. Five of the fifteen tests at 46 cm hit permafrost. Fourteen of the thirty tests at 15 cm recorded disturbed soils. These values show that the soil is relatively weak compared to other test sites.

Probe measurements (Table 5) were taken on 4 September 1977 and 18 August 1978. In 1977 the deepest permafrost was recorded at 9.6, 10 and 12

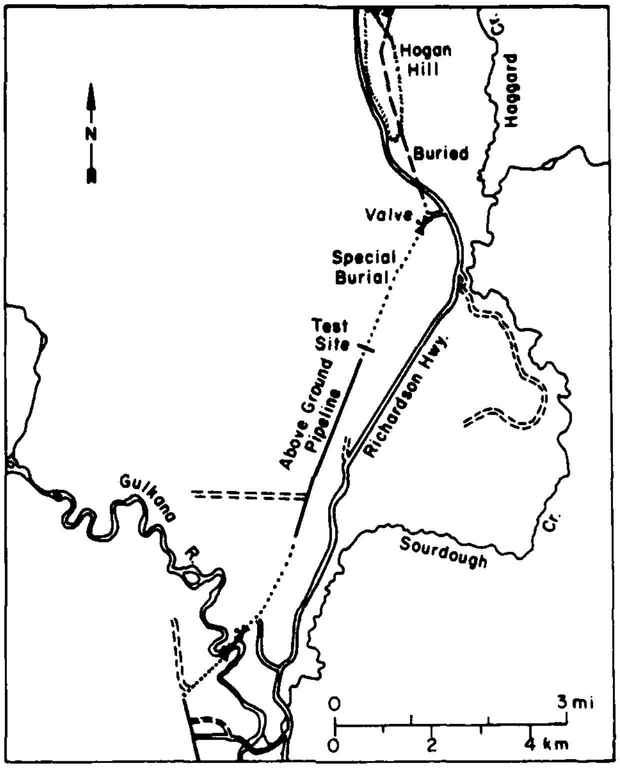


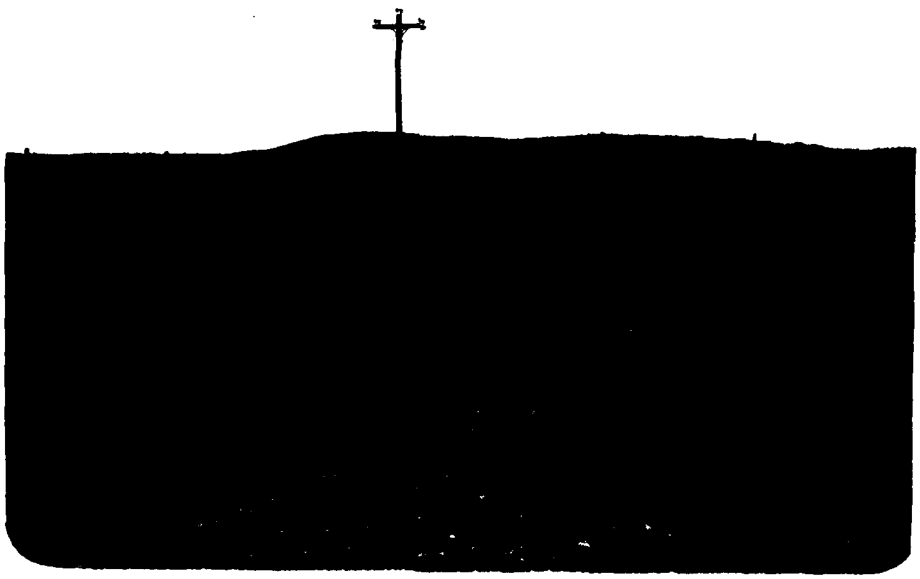
Figure 9. Hogan Hill test site location.

Table 3. Average difference in surface elevations, 1978 vs 1977 at Hogan Hill.

Baseline Station (m)	Number of Points	Average Difference 1978 vs 1977 (m)
0+00	9	-0.07*
0+10	11	-0.01
0+20	10	-0.01
0+30	11	-0.04
0+40	10	-0.03
0+50	9	-0.03
0+60	11	-0.03
0+70	9	-0.03
0+80	9	-0.04

*Negative values represent settlement.

a. Looking north along the centerline of the gravel berm over the buried pipeline section. Visible at the lower right are bulldozer cleat marks, indicating that the gravel surface had been reworked.



b. Looking north from the centerline of the buried pipeline along the west side. Note the shallow wheel ruts caused by traffic during the thaw season.

Figure 10. Hogan Hill site, September 1977.

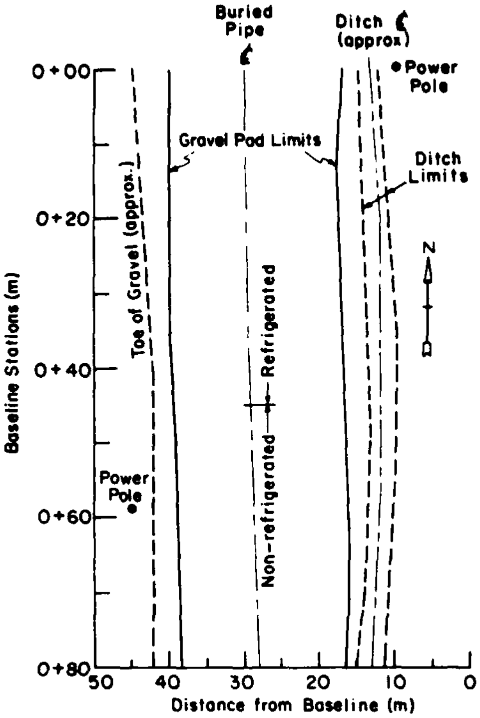
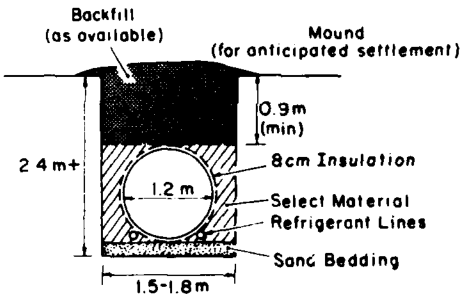
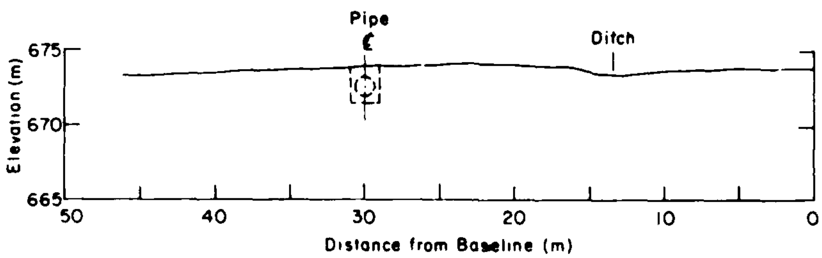


Figure 11. Plan view of the Hogan Hill site.



a. Standard design for the buried, refrigerated pipeline.



b. Elevations on a typical section (station 0+10), 4 September 1977.

Figure 12. Hogan Hill standard design and typical cross section

Table 4. Cone penetrometer measurements at Hogan Hill (4 September 1977).

Baseline Station (m)	Dist. from Baseline (m)	Soil strength (psi) 0	5	30	46 cm
0+00	0.0	0	39	60	pf*
0+10	0.0	0	30	70	pf
	11.0	0	Disturbed		
	11.5		Disturbed		
	1.2		Disturbed		
0+20	0.0	0	40	120	pf
	11.0	0	30	30	50
	12.0		Disturbed		
	14.0		Disturbed		
0+30	0.0	0	10	50	80
	9.6	0	40	60	120
	10.0		Disturbed		
	12.0		Disturbed		
0+40	0.0	0	40	50	pf
	9.3	0	50	40	60
	11.0		Disturbed		
	14.7		Disturbed		
0+50	0.0	0	20	50	pf
	9.0	0	30	60	80
	9.2		Disturbed		
0+60	0.0	0	30	40	80
	10.1	20	40	60	130
	10.5		Disturbed		
0+70	0.0	0	50	120	140
	10.7	0	40	50	60
	10.9		Disturbed		
0+80	0.0	0	10	pf	--
	11.9	0	30	35	60
	12.1		Disturbed		
	15.0		Disturbed		
Average:		1	33	60	86

* pf = permafrost

Table 5. Probe observations at Hogan Hill.

Baseline Station (m)	Dist. from Baseline (m)	Depth to permafrost (m) 4 Sept. 1977	18 Aug. 1978
0+00	0.0	0.51	0.57
0+10	0.0	0.47	0.53
	11.0	0.74	0.77
	11.5	0.81	0.95
	12.4		Too many rocks
0+20	0.0	0.50	0.48
	11.0	0.66	0.74
	12.0	0.77	0.88
	14.0	0.77	Too many rocks
0+30	0.0	0.53	0.48
	9.6	>1.19	1.48
	10.0	>1.19	1.45
	12.0	>1.19	>1.80
0+40	0.0	0.41	0.37
	9.3	0.77	1.80
	11.0	Rocks	1.60
	14.7		Too many rocks
0+50	0.0	0.47	0.50
	9.0	0.85	0.75
	9.2	0.75	0.83
0+60	0.0	0.51	0.51
	10.1	0.90	0.98
	10.5	0.80	0.99
0+70	0.0	0.51	0.56
	10.7	0.91	0.98
	10.9	0.86	0.91
0+80	0.0	0.35	0.45
	11.9	0.80	0.93
	12.1	0.69	0.75
	15.0		Too many rocks

m from baseline station 0+30. These points are either in or adjacent to the ditch at this station, and at this station this ditch is at a relatively low elevation. This may indicate the existence of ponding water during certain times of the summer, resulting in increased thaw depth. These points had deep permafrost in 1978, but the highest probe measurement was at baseline station 40. No radiation measurements were obtained at this test site.

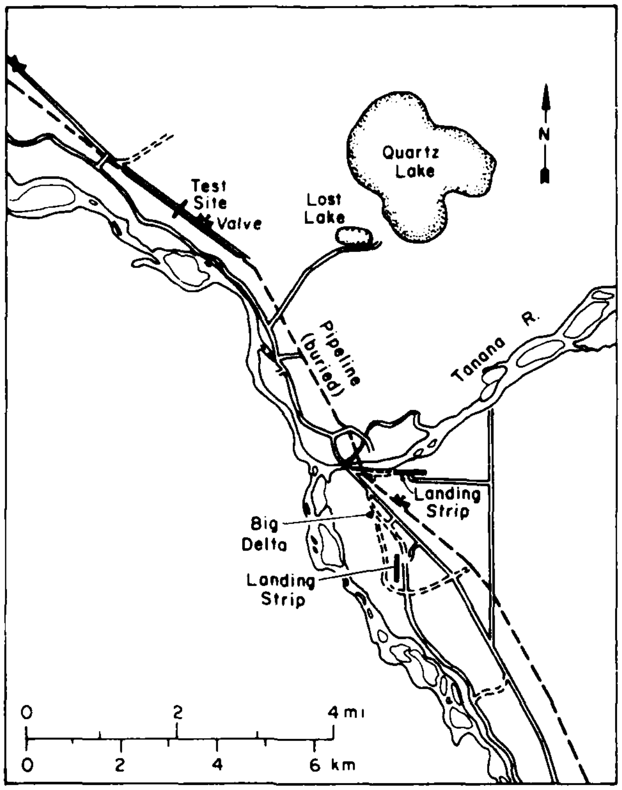


Figure 13. Quartz Lake test site location.

Quartz Lake

Figures 13 and 14 show the test site and surrounding area. The area included an above-ground section of pipeline, an open field, and an old trail crossing on its west side. A relatively thin fill, averaging about 0.8 m, was used in constructing the workpad at this location.

An APSC benchmark was installed in 1976; it is 11.25 m west of left VSM 64 and 12.05 m south of left VSM 65. The tagged benchmark projected 0.32 m above the ground surface in 1976. An exact elevation was not known, so an elevation of 30.48 m was arbitrarily assigned to this benchmark for producing the cross section and centerline profile data.

Surface elevations were measured on 23 August 1976, 5 September 1977 and 19 August 1978. Figure 15 is a plan view of the test site indicating VSM location, workpad edges, and toes of slopes. Figure 16 illustrates the longitudinal profiles at the east (right) VSMs and 10 m east of the east side VSMs, and Figure 17 shows typical VSM cross sections. In both figures, only the 1976 and 1977 data are shown; data for 1977 and 1978 show only very minor differences. The plots in Figure 17 show some unusual

a. Looking north from VSM Bent #62 along the east side of the workpad.

b. Looking north from VSM Bent #62 along the west side of the workpad.

Figure 14. Quartz Lake test site, September 1977.

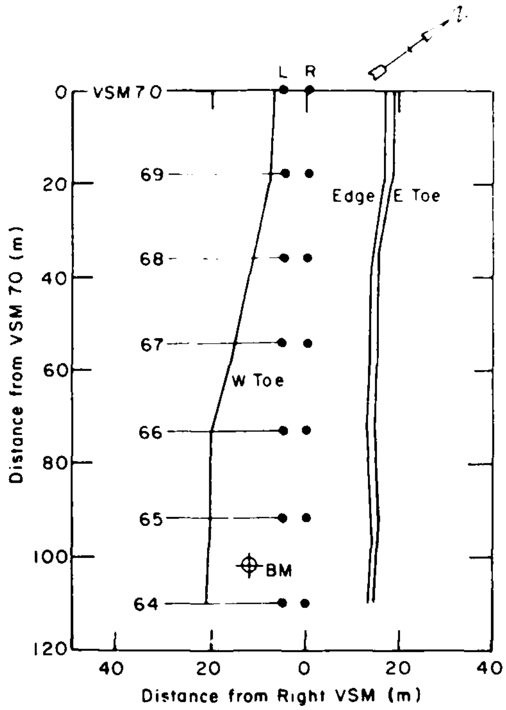


Figure 15. Plan view of the Quartz Lake test site.

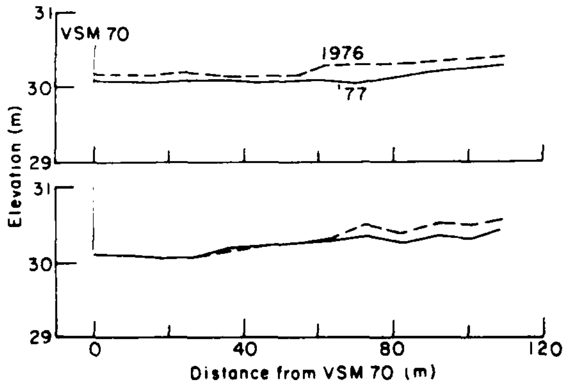


Figure 16. Elevations on longitudinal profiles. Quartz Lake. The upper profile is 10 m east of the right VSM; the lower profile is at the right VSM.

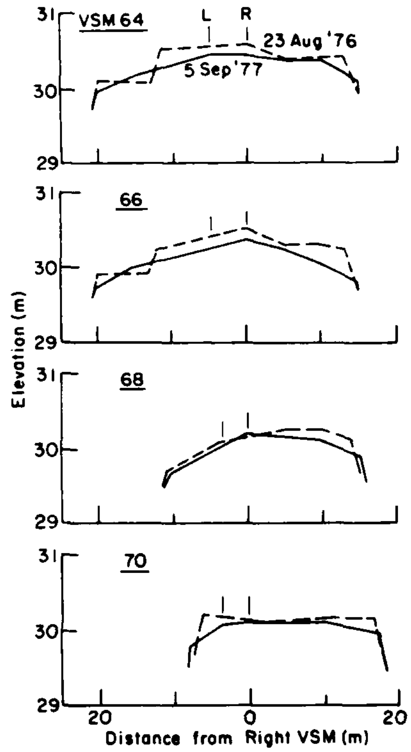


Figure 17. Typical cross sections at Quartz Lake.

variations between the 1976 and 1977 data. It is reasonable to assume that the surface was regraded at some time between the two surveys, and any subsequent comparisons of surface elevations should be made with respect to the 1977 data rather than that of 1976. The same assumption may be used to explain the variations along the longitudinal profiles shown in Figure 16.

Table 6. Cone penetrometer measurements at Quartz Lake (5 September 1977).

VSM No.	Dist. from Rt. VSM (m)	Soil strength (psi) 0	15	30	46 cm
64	16.1E	0	50	60	100
64	21.9W	0	100	120	130
65	16.8E	10	30	100	140
65	21.4W	0	40	120	140
66	16.2E	0	50	80	80
66	21.6W	10	40	100	140
67	16.5E	20	130	150	160
67	16.7W	10	50	140	180
68	17.2E	0	20	100	120
68	12.4W	20	70	110	130
69	19.6E	0	140	160	180
69	9.9W	0	10	100	120
70	19.3E	0	40	90	100
70	9.2W	0	120	120	120
Average:		5	64	111	131

Table 7. Radiation measurements at Quartz Lake (5 September 1977).

	Radiation (Btu/ft^2 hr) Incident	Reflected	Albedo	Comments
Road	145	32	0.22	--
Road with grass	145	37	0.26	Seeded
Cleared	160	30	0.19	No trees

Cone penetrometer readings (Table 6) were obtained in September 1977. The highest readings were at 16.7 m west of VSM 67 and 19.6 m east of VSM 69, where subsurface soils contain coarse-grained granular materials. Solar radiation measurements were taken on the bare roadway, the roadway with grass, and a surface where trees and high brush only had been removed. The reflected values were relatively low compared to the incident radiation readings (Table 7).

Probe observations were also obtained on the VSM 64-70 cross sections (Table 8). These data show a pronounced difference between points on the east and those on the west. Figure 13 show that the "east" and "west" designations are somewhat misleading. At least part, if not all, of the

Table 8. Probe observations at Quartz Lake.

VSM No.	Undisturbed area* Dist. from Rt. VSM (m)	Depth to permafrost (m) 5 Sep 77	Depth to permafrost (m) 19 Aug 78	Toe area Dist. from Rt. VSM (m)	Depth to permafrost (m) 5 Sep 77	Depth to permafrost (m) 19 Aug 78
64	16.1E	0.51	0.54	15.1E	0.79	0.84
64	21.9W	0.79	1.37	20.9W	>1.19	1.53
65	16.8E	0.60	0.56	15.8E	0.90	0.95
65	21.4W	0.65	1.33	20.4W	>1.19	1.41
66	16.2E	0.62	0.66	15.2E	0.91	0.95
66	21.6W	0.76	1.18	20.6W	1.10	1.35
67	16.5E	0.61	0.60	15.5E	0.99	1.03
67	16.7W	0.67	1.18	15.7W	1.10	1.22
68	17.2E	0.43	0.56	16.2E	0.72	0.83
68	12.4W	0.75	1.15	11.4W	1.10	1.23
69	19.6E	0.53	0.53	18.6E	0.92	0.97
69	9.9W	0.88	1.18	8.9W	1.07	1.24
70	19.9E	0.57	0.48	18.5E	0.94	0.87
70	9.2W	0.85	1.30	8.2W	1.09	1.30
Averages:	East	0.55	0.56	East	0.88	0.92
	West	0.76	1.24	West	1.12+	1.33
	All	0.66	0.90	All	1.00	1.12

* 1978 undisturbed reading may be affected by utility posts lying on the ground.

difference may be because the "west" points are actually on the southern side of the site. The northern side would tend to be shaded from the sun, reducing the thaw on that side. The average difference in 1977 between the east and west points in the undisturbed area was 0.21 m and 0.24 m at toe locations. In 1978 essentially no increase in the depth of thaw was noted on the east side, while the depth of thaw on the west averaged 0.48 m more in the undisturbed areas and about 0.2 m at toe locations.

Eielson Air Force Base

Figures 18 and 19 show this buried pipeline test site along with some identifying features. A temporary benchmark, numbered 56-17-75, was established during the September 1976 survey. The benchmark is the top of a spike in a black spruce tree 15 cm in diameter, approximately 1.5 m east

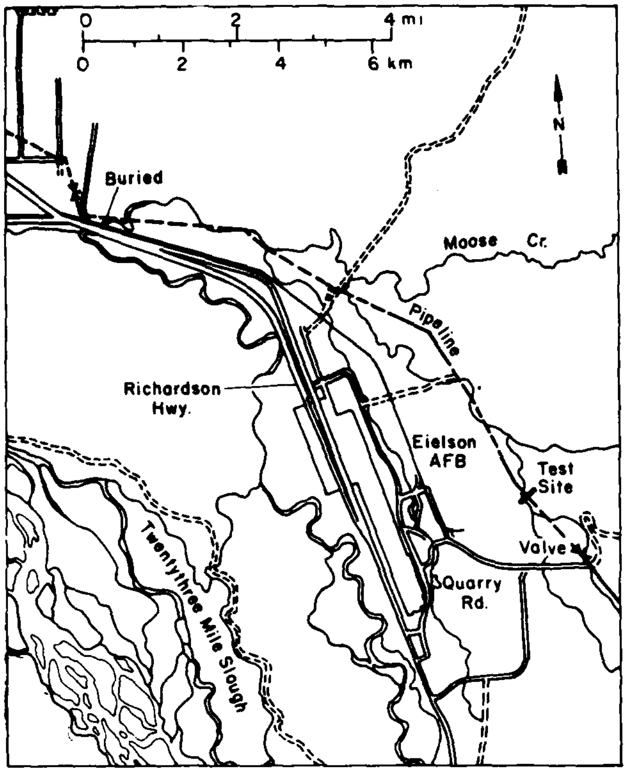


Figure 18. Eielson Air Force Base site location.

of the workpad and 96 m north of the thermocouple installation. The top of the spike is 38 cm above the ground surface. The actual elevation was not known, so an elevation of 30.48 m was assigned to this benchmark for survey purposes.

A plan view of the workpad test site is shown in Figure 20, illustrating the lateral extent of the workpad and the centerline of the buried pipe. Surface elevations were measured on 6 September 1977 and 19 August 1978.

The data show essentially no differences between the 1977 and 1978 elevations, so neither graphs nor tables are presented. Figure 21 shows details of the standard design for a buried pipeline segment and a cross section typical for the site.

Table 9 shows the cone penetrometer measurements. The highest cone penetrometer value was recorded 19.6 m west of the 10 m station at 46 cm. Other high penetrometer readings were obtained at the 0+40, 0+50 and 0+60 m stations, all on the west side of the pipeline and at depths of 46 cm.

a. Looking north along the centerline of the pipe from about 90 m south of centerline station 0+30. The post and sign (marking the temperature sensors) are at station 0+30.

b. Looking east along the workpad 90 m south of centerline station 0+30. Grader tracks are visible in the lower right, indicating that the surface was reworked before the 1977 survey.

Figure 19. Eielson Air Force Base site, September 1977.

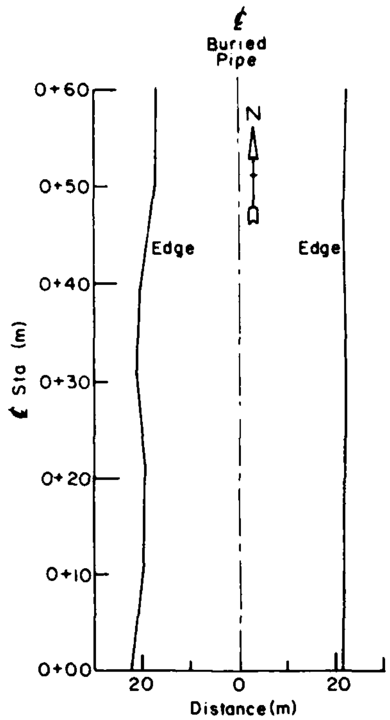
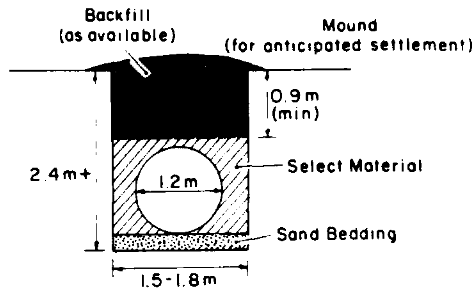
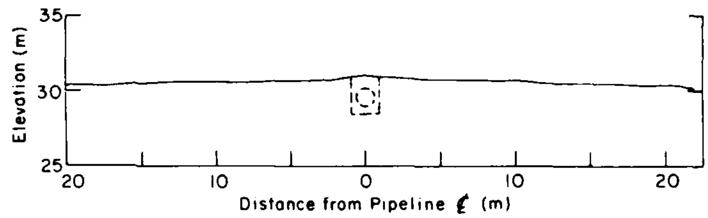


Figure 20. Plan view of the Eielson Air Force Base test site.



a. Standard design for the buried pipeline.



b. Elevations on a typical section (station 0+40), 19 August 1978.

Figure 21. Eielson Air Force Base standard design and typical cross section.

Table 9. Cone penetrometer measurements at Eielson Air Force Base (19 August 1978).

Centerline station (m)	Dist. from centerline (m)	Soil strength (psi) 0	15	30	46 cm
0+00	22.0W	70	110	200	200
0+00	21.3E	0	50	110	160
0+10	19.6W	90	100	210	270
0+10	21.4E	0	90	120	140
0+20	19.0W		Too much gravel		
0+20	21.6E	0	30	80	150
0+30	21.0W	60	140	180	190
0+30	21.9E	0	30	60	130
0+40	20.0W	80	160	170	220
0+40	21.9E	0	90	180	210
0+50	17.0W	40	50	180	220
0+50	21.6E	0	20	70	150
0+60	17.0W	120	80	160	220
0+60	22.0E	0	70	160	140
Average:		35	78	145	185

Table 10. Probe observations at Eielson Air Force Base.

Station (m)	Undisturbed area: Dist. from centerline (m)	Undisturbed area: Depth to permafrost (m) 5 Sept. 1977	19 Aug. 1978	Toe area: Dist. from centerline (m)	Toe area: Depth to Permafrost (m) 5 Sep. 1977	19 Sept. 1978
0+00	22.0W	0.84	1.19	20.0W	0.83	0.71*
0+00	21.3E	0.66	0.57	20.3E	>1.19	1.01
0+10	19.6W	0.69	0.82	18.6W	0.72	0.77
0+10	21.4E	0.74	0.97	20.4E	1.04	1.10
0+20	19.0W	0.94	1.00	13.1W	--	1.24
0+20	21.6E	0.76	0.61	20.6E	0.87	0.89
0+30	21.0W	1.05	0.97	13.3W	Gravel	1.10
0+30	21.9E	0.80	0.54	20.9E	0.91	0.90
0+40	20.0W	0.70	0.81	13.4W	>1.19	1.08
0+40	21.9E	0.70	0.53	20.9E	0.89	0.89
0+50	17.0W	Gravel*	0.87	13.1W	1.00	1.00
0+50	21.6E	0.69	0.77	20.6E	0.88	0.81
0+60	17.0W	Gravel*	0.87	13.0W	0.77	--
0+60	22.0E	0.61	0.42	20.4E	0.93	0.98
Average:		0.76	0.78		0.94	0.96

* No organic surface layer

The deepest toe probe measurements (Table 10) were 20.3 m east of station 0+00 m, 20.4 m east of station 0+10 m, 13.1 west of station 0+20 m, and 13.4 west of station 0+40 m in both 1977 and 1978; these measurements were between 1.01 m and 1.24 m. Surface albedo and other radiation measurements were not taken because a nearby forest fire caused smokey conditions during the 1977 survey.

Engineer Creek

This test area is an above-ground pipeline workpad site (Fig. 22 and 23). It is due east of the former Alyeska VSM Load Test building. A temporary benchmark (TBM) was established in August 1976. The benchmark is the top of a horizontal spike in the side of a black spruce tree 15 cm in diameter, 4.6 m from the east toe south of VSM 45. The TBM is set at an elevation of 275.41 m and was measured as 0.95 m above the ground surface in August 1976.

Surface elevations were measured on 22 August 1976, 5 September 1977 and 20 August 1978. Figure 24 shows the plan view of the test site, indi-

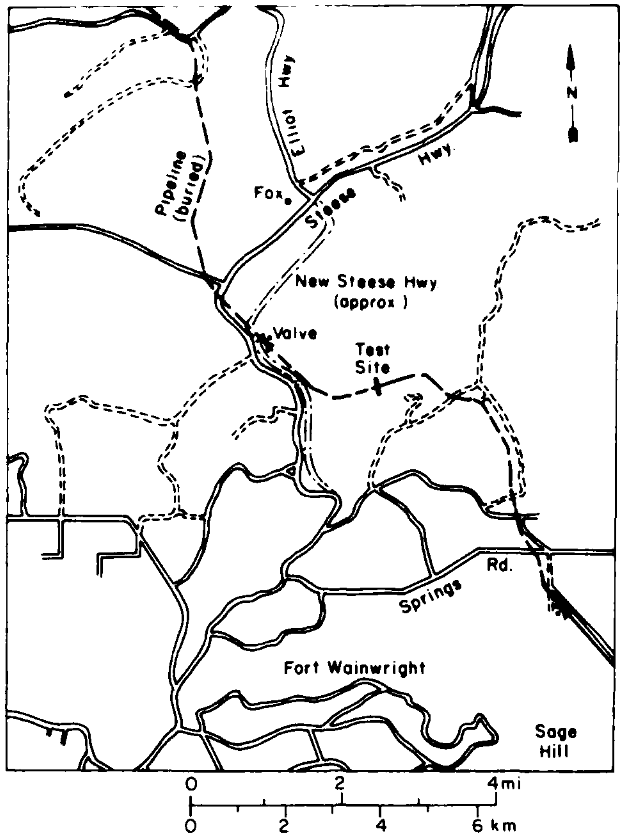
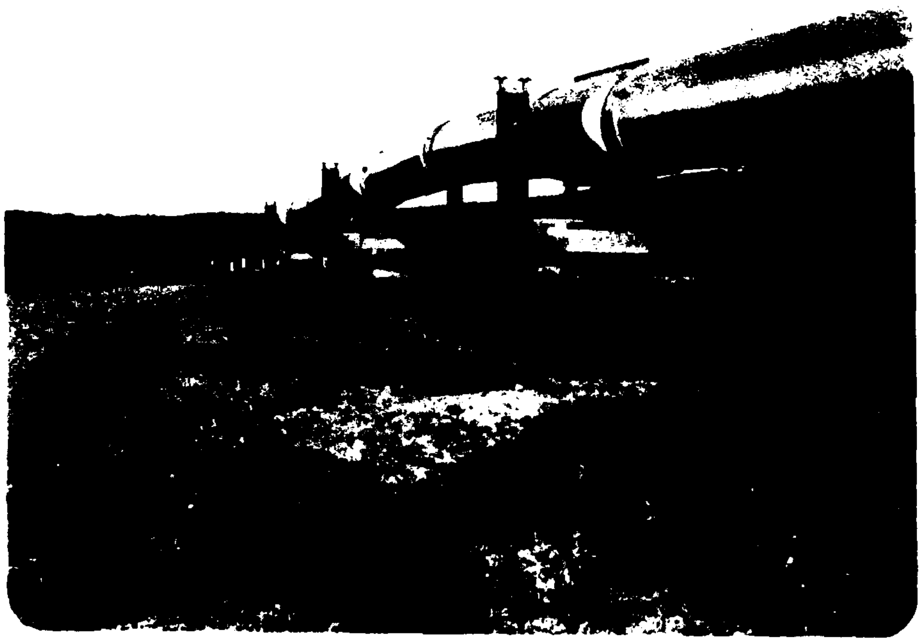


Figure 22. Engineer Creek test site location.

cating the workpad edges, slope toes and VSM locations. Average differences in surface elevations on cross sections and longitudinal profiles are shown in Table 11. A typical cross section is shown in Figure 25 and the longitudinal profile at the right VSMs for 1978 is shown in Figure 26. The level observations indicate a small amount (averaging about 5 cm) of settlement occurring in the first year (1976 to 1977), with no change in the second year. Regrading of the surface, occurring sometime between the 1976 and 1977 surveys, may have been responsible for all or part of the observed settlement.

Table 12 shows the cone penetrometer measurements for this test site. The readings are lower than from most of the other southern test sites, possibly because permafrost exists within about 46 cm of the undisturbed surface. Probe measurements conducted during the 1977 and 1978 surveys

a. Looking east along the north side of the workpad from near VSM #48.



b. Looking east from near VSM #48 on the north side of the pipe.

Figure 23. Engineer Creek site, 5 September 1977.

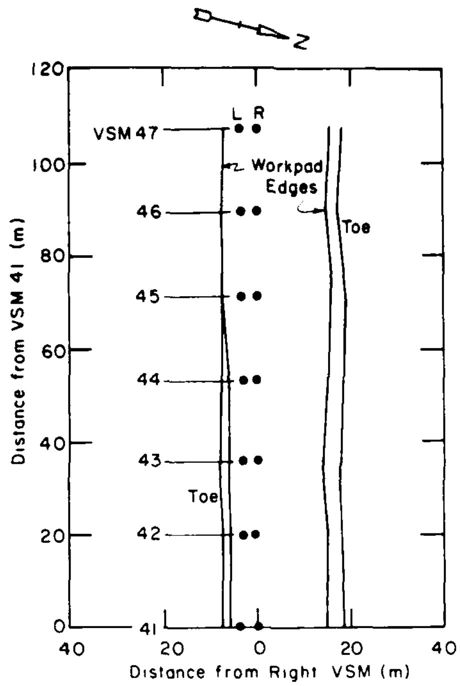


Figure 24. Plan view of the Engineer Creek site.

Table 11. Average difference in surface elevations 1977 and 1978 vs 1976 at Engineer Creek.

VSM No.	Number of Points	Average Difference (m)	
		1977 vs 1976	1978 vs 1976
41	8	-0.08*	-0.11
42	8	-0.04	-0.04
43	8	-0.04	-0.05
44	8	-0.02	-0.02
45	7	-0.05	-0.05
46	7	-0.06	-0.05
47	7	-0.08	-0.09
Right VSMs	13	-0.02	-0.02
10 m North of Right VSMs	13	-0.06	-0.07

*Negative values represent settlement

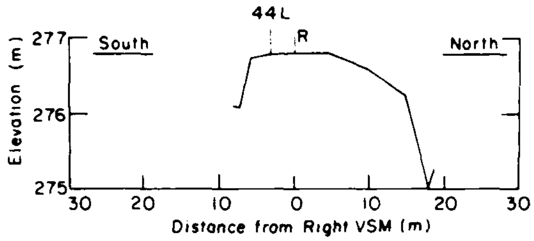


Figure 25. Surface elevations on a typical cross section (VSM #44) for 1978, Engineer Creek.

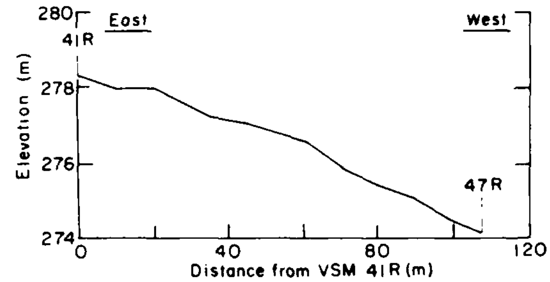


Figure 26. Surface elevations on a longitudinal profile at the right VSMs for 1978, Engineer Creek.

Table 12. Cone penetrometer measurements at Engineer Creek (5 September 1977).

VSM No.	Dist. from Rt. VSM	Soil strength (psi) 0	15	30	46 cm
41	19.2R	30	90	110	100
41	8.2L	20	40	70	pf*
42	19.2R	10	35	55	pf
42	8.0L	0	50	100	120
43	18.3R	0	20	70	pf
43	8.9L	10	80	100	120
44	18.8R	0	30	90	pf
44	8.5L		Disturbed		
45	19.7L	0	30	50	pf
45	8.4L	0	60	100	pf
46	17.7R	0	10	40	180
46	8.6L	0	10	80	pf
47	18.7R	0	30	70	40
47	8.3L	40	50	80	pf
Average:		8	41	78	112

* permafrost

(Table 13) found the permafrost at the toe of the slope to be the deepest to the left (south) of VSMs 43, 44, 46 and 47. For the undisturbed locations the deepest probe measurements were to the left (south) of VSMs 42, 43 and 47. Average values in 1978 for the undisturbed area and toe of the slope are 52 cm and 92 cm, respectively. In general, thaw on the south side of the workpad averaged 0.1 to 0.3 m deeper than on the north.

Table 13. Probe observations at Engineer Creek (20 August 1978).

	Undisturbed Area			Toe Area		
		Depth to permafrost (m)			Depth to permafrost (m)	
VSM No.	Dist. from Rt. VSM (m)	5 Sept. 1977	20 Aug. 1978	Dist. from Rt. VSM (m)	5 Sept. 1977	20 Aug. 1978
41	19.2R	0.57	0.44	18.2R	0.73	0.82
41	8.2L	0.50	0.41	7.2L	0.79	1.06
42	19.2R	0.48	0.50	18.2R	0.60	0.86
42	8.0L	0.65	0.63	7.0L	0.92	0.92
43	18.3R	0.37	0.41	17.3R	0.71	0.77
43	8.9L	0.62	0.67	7.9L	1.09	1.07
44	18.8R	0.43	0.54	17.8R	0.57	0.67
44	8.5L	Disturbed	0.98	7.5L	>1.19	1.07
45	19.7R	0.46	0.53	18.7R	0.66	0.84
45	8.4L	0.48	0.49	7.4L	0.80	0.88
46	17.7R	0.44	0.44	16.7R	0.71	0.85
46	8.6L	0.47	0.54	7.6L	1.03	1.09
47	18.7R	0.37	0.49	17.7R	0.65	0.84
47	8.3L	0.57	0.65	7.3L	1.10	1.17
Average All:		0.49	0.52		0.83	0.92
Left (south):		0.55	0.56		0.99	1.04
Right (north):		0.45	0.48		0.66	0.81

TAPS Road Mile 16.3

Figure 27 is a map of this test site. CRREL selected this area for study following the completion of the road, and surface elevations have been measured annually since 1970. Data collected during 1970 to 1975 were summarized by Berg and Smith (1976). The right-of-way was cleared and stripped over a width of about 50 m (approximately 30 m west and 20 m east of the centerline); the stripped material was replaced after construction of the road embankment and seeded during the 1970 summer. An average of 1.5 m of fill was used in the construction of the roadway on a subgrade that had a relatively high ice content.

A temporary benchmark is the top of a spike located at ground level in a spruce tree 8 cm in diameter, which was cut off 91 cm above ground. The TBM has an elevation of 493.36 m and is located about 32 m west of the road centerline at station 869+70.

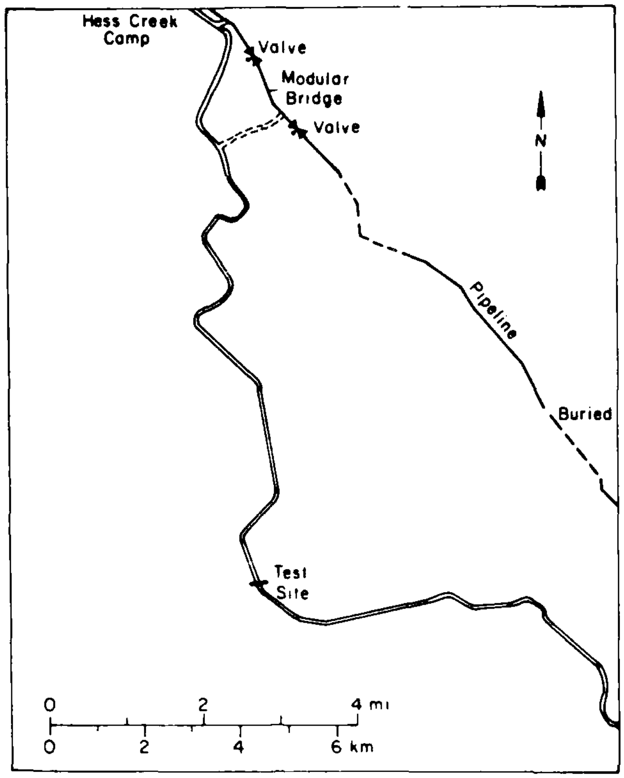


Figure 27. TAPS Road mile 16.3 test site location.

The nearest NGS benchmark is stamped W162 1975 and is located at milepost 16, 63.33 km south along the TAPS Road from the south end of the bridge over the Yukon River. It is 12.8 m southwest of the centerline of the road, 24.5 m west of and across the road from the milepost, and about 30 cm higher than the road; it is a disk on the top of a copper-coated rod driven to a depth of 2.1 m. The disk projects 9 cm above the ground. It was established in August 1975.

The gravel surface roadway (Fig. 28) was frequently regraded to maintain a relatively smooth surface, creating berms on both sides of the roadway. These berms inhibit water runoff to the roadside slopes and edges and allow excess water to enter the subgrade vertically or produce potholes in the roadway surface.

During this phase of the study, surface elevations were measured on 21 August 1976, 9 September 1977 and 20 August 1978. No centerline surveys were performed at this site. Figure 29 shows a plan view of the roadway, indicating the centerline, the edge of the road, and the toes of slopes as

a. Looking north along the west side of the road. Note the shallow berm along the roadside created during grading.

b. Looking northeast along the west shoulder of the road.

Figure 28. TAPS Road mile 16.3 site, 3 September 1977.

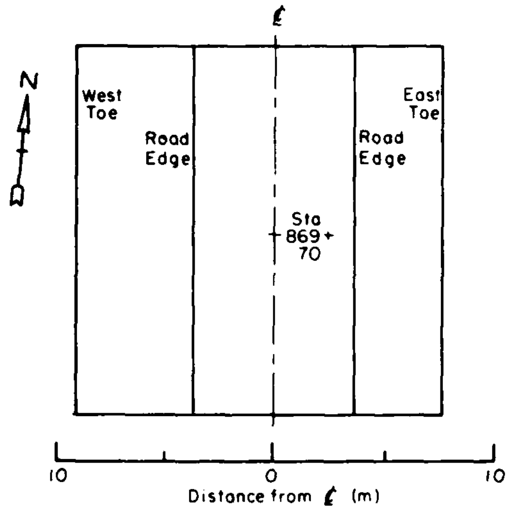


Figure 29. Plan view of the TAPS Road mile 16.3 site.

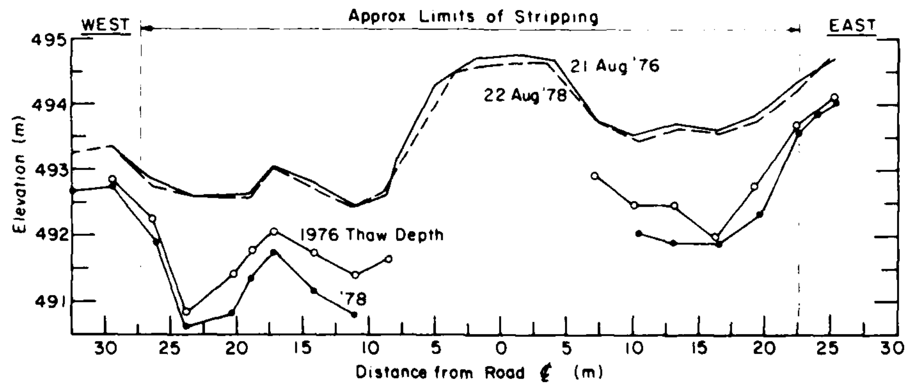


Figure 30. Surface elevations and thaw depths, 1976 and 1978, TAPS Road mile 16.3.

of the 1978 survey. Figure 30 shows surface elevations and thaw depths for 1976 and 1978; in general the 1977 elevations are midway between those for 1976 and 1978. The road surface appears to have settled about 10 cm in the two-year period, but part of this may be attributable to regrading of the surface. Outside the road embankment, the settlement averaged a little less than 10 cm on the east side and considerably less on the west side, in spite of the fact that the thaw depth lowered an average of about 40 cm within the limits of stripping. This probably indicates that the soil layer contained little excess moisture in the frozen state. Figure 31 shows surface elevations for 1970, 1974 and 1978 and thaw depths for 1976 and 1978. Settlement of the road surface has been relatively uniform, averaging a little over 0.3 m during the eight-year period. Note that the width

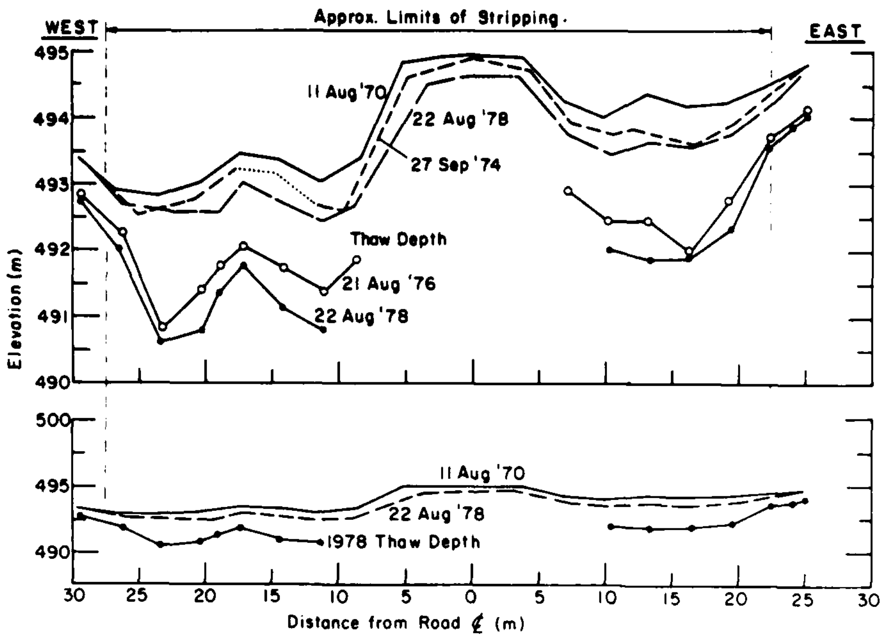


Figure 31. Elevations on cross section, 1970-1978, TAPS Road 16.3. The upper cross section has a scale of 1 vertical = 5 horizontal; the lower cross section has a scale of vertical = horizontal.

of the roadway has apparently decreased from about 9 m in 1974 to about 7 m in 1978. The 7-m width did not show up in the surveys until 1977,but the 1976 survey (Fig. 30) seems to indicate that the west shoulder was settling. It is possible that the west shoulder was graded to correct the sloughing sometime between the 1976 and 1977 surveys, resulting in the narrowing of the road bed and some slight raising of the surface due to material moved up from the shoulder area. Settlement of the surface on either side of the road embankment between 1970 and 1978 averaged somewhat higher than that of the embankment -- about 0.6 m between 10 and 20 m east of the centerline and about 0.5 m between 10 and 20 m west of the centerline. Outside the limits of stripping, there has been little change in surface elevation or depth of thaw during the eight-year period.

Figure 31 also shows the 1970 and 1978 surface elevations and the 1978 thaw depths plotted to a scale of 1 m vertical equals 1 m horizontal. This figure shows clearly that the embankment has settled less than the adjacent surfaces, and it is reasonable to assume that thaw beneath the embankment has progressed at a slower rate.

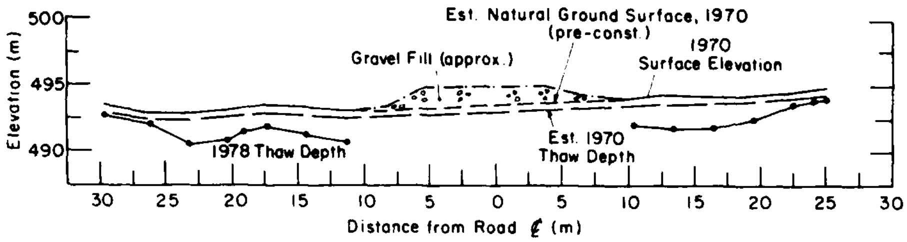


Figure 32. Initial conditions and 1978 thaw depth, TAPS Road mile 16.3

Table 14. Cone penetrometer measurements at TAPS Road Mile 16.3 (9 September 1977).

Dist. from centerline (m)	Soil strength (psi) surf.	15	30	46 cm
32.5W	0	110	150	100
29.5W	0	30	150	100
26.5W*	20	100	120	140
22.3E	0	40	70	110
23.9E (stake)	0	100	80	120
25.1E	0	120	140	140
Average:	3	83	118	118

* Soil strength between 23.4W and 193E could not be measured because the surface was too rocky.

Figure 32 shows the approximate initial conditions at the site, including the estimated preconstruction thaw depth and natural ground surface under the embankment section. The 1978 thaw depth is also shown to illustrate permafrost degradation occurring during the eight years following construction.

Cone penetrometer measurements are shown in Table 14. Rocky surface conditions prevented tests from being performed between 23.4 m west and 19.3 m east of the centerline. Probe readings taken annually (Table 15) showed an increase in the depth of thaw each season. Equal amounts of solar radiation were absorbed by the road, the roadside and undisturbed areas, as shown in Table 16. However, the roadside and undisturbed area

Table 15. Probe observations at TAPS Road Mile 16.3.

Distance from centerline (m)		Depth to permafrost (m) 21 Aug 1976	9 Sep 1977	22 Aug 1978
32.5W		-	0.47	0.59
29.5W		0.50	0.53	0.62
26.5W		0.60	1.17	0.80
23.4W		1.76	>1.19	2.00
20.4W		1.23	>1.19	1.79
19.0W		0.87	1.04	1.20
17.3W		0.98	1.14	1.25
14.4W		1.07	>1.19	1.58
11.3W		1.06	>1.19	1.67
9.0W		0.92	>1.19	-
10.2E		1.07	>1.19	1.42
13.3E		1.25	>1.19	1.76
16.3E		1.63*	>1.19	1.68
19.3E		1.08	>1.19	1.46
22.3E		0.65	0.66	0.67
23.9E		-	0.64	0.66
25.1E		0.62	0.69	0.67
Averages:	West	1.00	Insufficient	1.28
	East	1.05	data	1.19
	All	1.02		1.24

*Approximately 5 cm water at surface.

Table 16. Radiation measurements at TAPS Road Mile 16.3 (9 September 1977).

	Radiation (Btu/ft^2-hr) Incident	Reflected
Road	120	25
Roadside	120	28
Undisturbed	120	15

had the highest and lowest reflected radiation values, respectively. Surface temperatures adjacent to the road were lower because of evaporation, evapotranspiration and the insulating effect of the vegetation.

TAPS Road Mile 50.7

Figure 33 is a map of this test site, showing the pipeline route and the Yukon River. This site (Fig. 34) was selected for study in June 1970 and has been monitored annually. This section of road is located in a relatively flat area. The trees and vegetation were disturbed during construction for a width of only about 6 m beyond the toe of the slope on each side of the road embankment. Approximately 1.5 m of fill was used in the construction of the roadway. Data collected during 1970 to 1975 were summarized by Berg and Smith (1976).

A temporary benchmark was established in 1970. The TBM is the top of a spike in a stump of a spruce 10 cm in diameter, 50.3 m left of station 2710+00. It has an elevation of 357.01 m and is on the north side of the road.

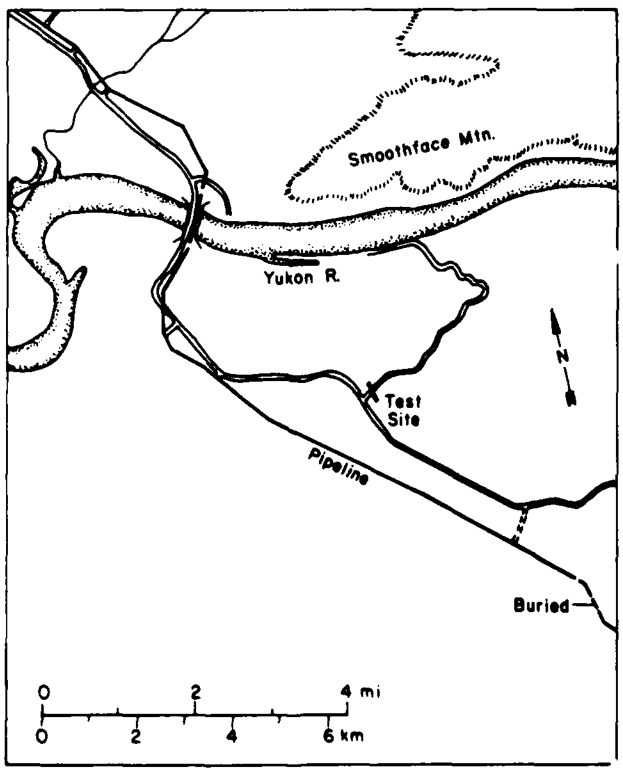


Figure 33. TAPS Road mile 50.7 test site location.

a. Looking toward the south side of the road from the centerline. Note the stones along the edge.

b. Looking toward the north side of the road from the centerline. Note the gravel berm along the edge resulting from grading.

Figure 34. TAPS Road mile 50.7, 3 September 1977.

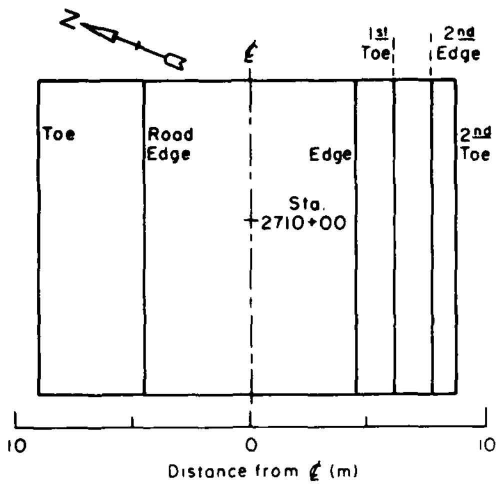


Figure 35. Plan view of the TAPS Road mile 50.7 site.

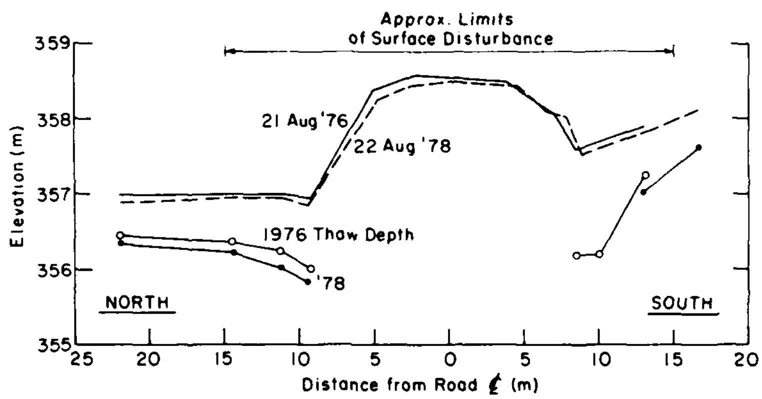


Figure 36. Surface elevations and thaw depths, 1976 and 1978, TAPS Road mile 50.7.

A plan view indicating the original road edges and the toes of slope is shown in Figure 35. During this phase of the study, surface elevations were measured on the cross section only on 21 August 1976, 3 September 1977 and 20 August 1978. Figure 36 shows the 1976 and 1978 surface elevations and thaw depths; in general, the 1977 elevations are midway between those for 1976 and 1978. During this two-year period, the settlement of the surface was relatively uniform across the entire cross section, averaging about 10 cm. Thaw depths on the north side of the embankment lowered somewhat more than the surface did, especially near the north toe of slope. There were not enough probings on the south side to allow comparison of the two years' data.

Figure 37 shows surface elevations for 1970, 1975 and 1978, and the 1976 and 1978 thaw depths. Settlement of the road embankment was relatively uniform and averaged about 0.4 m over the eight-year period. The width of the road surface was reduced to some extent, probably due to periodic grading work, particularly along the side slopes. It appears unlikely that new material was added to the road surface, but material may have been brought up to the road surface from the side slopes. Field notes indicate this may have occurred in 1976 and could have resulted in raising the road surface by several centimeters. Settlement outside the road embankment during 1970 to 1978 appears to have been somewhat less than that for the embankment, averaging as little as 0.2 m.

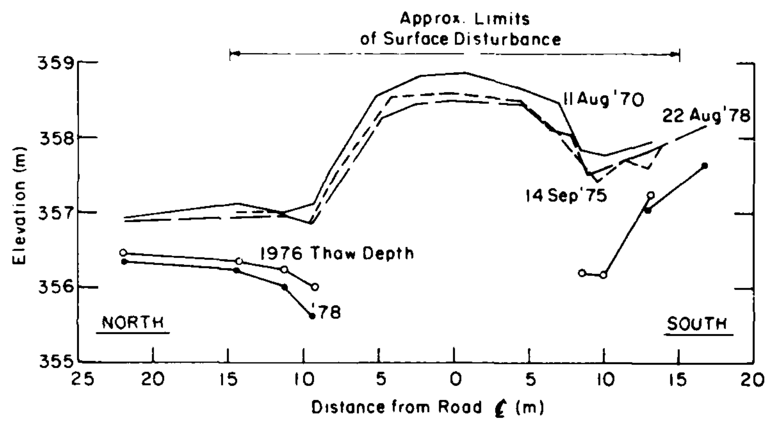


Figure 37. Surface elevations and thaw depths, 1970-1978, TAPS Road mile 50.7.

Cone penetrometer and probe measurements (Tables 17 and 18) were obtained at the same time the level survey was conducted. Penetrometer tests were not performed between 9.3 m north and 8.6 m south of the centerline because of rocky conditions in this area. Permafrost existed at 46 cm below the gravel surface at 16.7 m south of the centerline. The highest probe reading during the 1978 survey was at the slope toe 9.3 m north.

Old Man Airfield

Old Man Airfield is approximately 17 km south of the Arctic Circle and located in the subarctic region of Alaska (Fig. 1). It was built primarily as a landing strip for planes transporting pipeline equipment during construction of the trans-Alaska pipeline.

Table 17. Cone penetrometer measurements at TAPS Road Mile 50.7 (3 September 1977).

Dist. from centerline (m)	Soil strength (psi)			
	0	15	30	46 cm
22.0N	0	70	80	80
14.3N	0	120	120	90
11.2N*	0	90	160	140
13.0S	0	120	180	150
16.7S	0	110	130	pf†
Average:	0	102	134	115

* Soil strength between 9.3N and 8.6S could not be measured because the surface was too rocky.
† Permafrost.

Table 18. Probe observations at TAPS Road Mile 50.7.

Dist. from centerline (m)	Depth to permafrost (m)		
	21 Aug. 1976	3 Sept 1977	22 Aug. 1978
22.0N	0.54	0.56	0.52
14.3N	0.65	0.75	0.72
11.2N	0.76	1.09	0.92
9.3N (Toe)	0.93	>1.19	1.24
8.6S (Toe)	1.41	>1.19	---
10.0S	1.50	---	---
13.0S	0.65	0.74	0.76
16.7S	---	0.49	0.52

Figure 38 shows the airfield runway and the general location of the two test sites at runway stations 14+00 and 36+00, east and west sites, respectively. Figure 39 shows surface conditions at the sites, and Figure 40 shows plan views of these test sections indicating original runway edges and toes of slopes of the runway embankment.

For the west test section a temporary benchmark was established in the fall 1976 survey. The tagged benchmark is the top of a stake on the north side of the runway, and since an exact elevation could not be determined, an elevation of 30.48 m was assigned for producing the profiles and cross sections. For the east test section the temporary benchmark is the top of

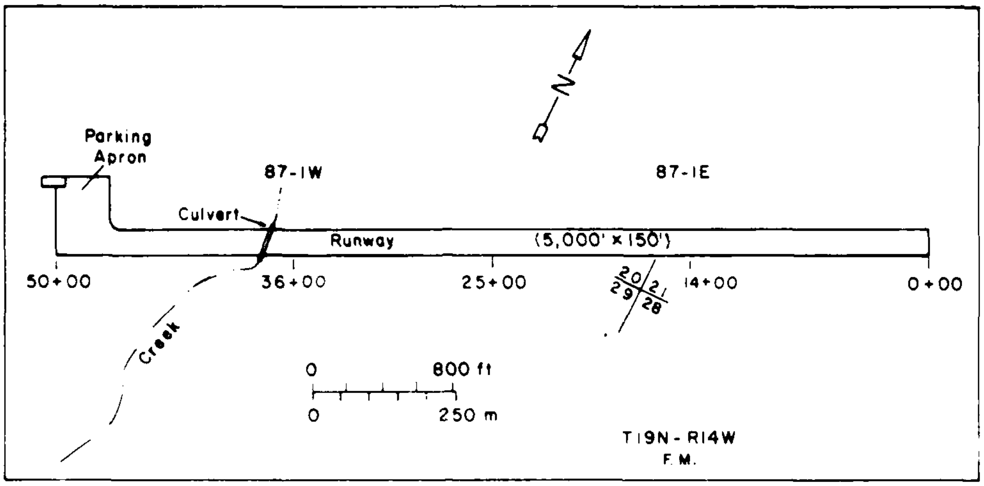


Figure 38. Plan view of the Old Man Airfield test sites 87-1E and 87-1W.

a. East site, looking south from the south side of the runway along the cross section. Note the gravel berm at the edge created by regrading. The pipeline is visible at the upper right.

Figure 39. Old Man Airfield east and west sites.

b. East site, looking west from the cross section along the north side of the runway. Note the cracks along the runway edge, probably caused by the settlement at the toe area. Also note the surface water along the toe.

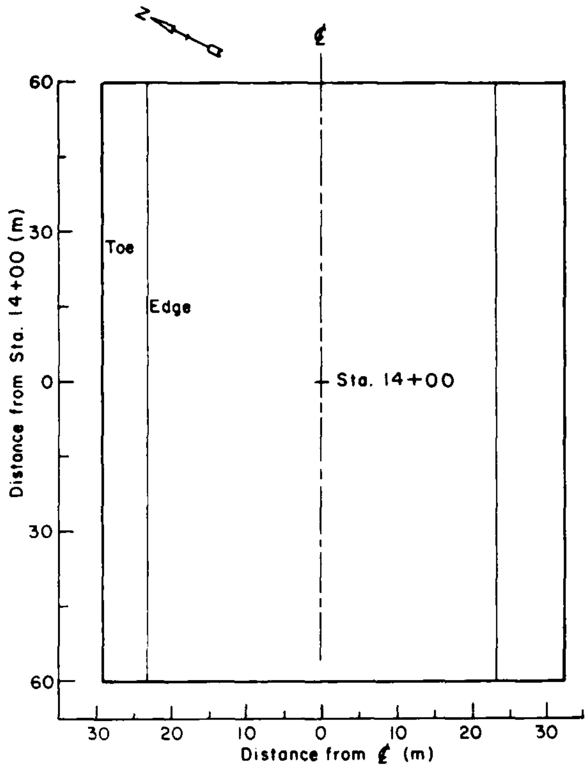
c. East site, looking north from the north side of the runway along the cross section. Surface water is visible at the toe.

Figure 39 (cont'd). Old Man Airfield east and west sites.

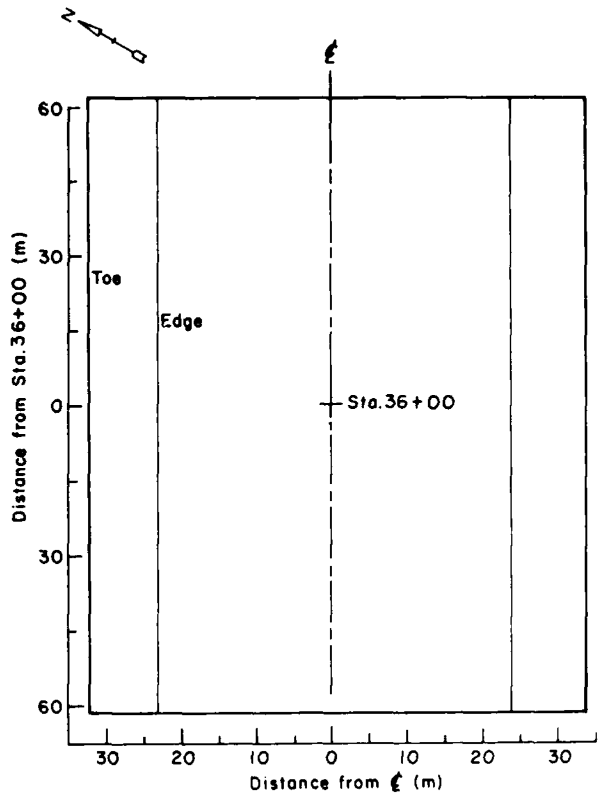
d. West site, looking south from 6 m north of the runway edge on the cross section line.

e. West site, looking north from 6 m south of the north edge of the runway on the cross section line. Note the surface water at the toe.

Figure 39 (cont'd).



a. East site.



b. West site.

Figure 40. Plan view of the Old Man Airfield test sites.

a stake on the north side of the runway and has an assigned elevation of 30.48 m.

The nearest NGS benchmark, stamped N160 174, is 50.1 km south along the Haul Road from the junction of the entrance road at Pump Station 5 and was established in August 1975. It is 0.8 km southeast of the southeast entrance road to Old Man Camp, 1.2 km northwest of the bridge over the Kanuti River, 24.8 m southwest of the centerline of the road, and about 0.3 m lower than the road surface. It is a disk on a copper-coated rod driven to a depth of 4.88 m. The disk projects 18 cm above the ground.

Surveys of centerline profiles and cross section surface elevations were conducted on 21 August 1976, 5 September 1977, and 23 August 1978. Figure 41 compares surface elevations recorded in 1976 and 1978 for the centerline profile at the east site (87-1E) and for the runway cross section (station 14+00). It appears that considerable settlement had occurred at this site, but movement of the benchmark between 1977 and 1978 was prob-

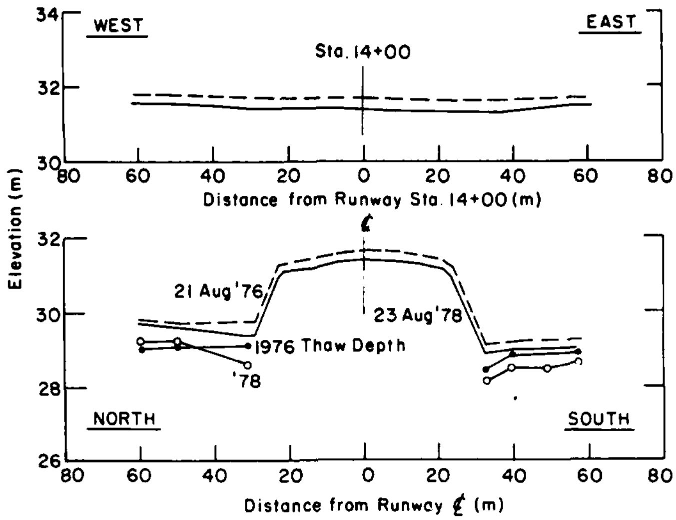


Figure 41. Surface elevations of the east site, Old Man Airfield. The upper drawing is the centerline profile; the lower drawing is the cross section at runway station 14+00.

ably responsible for most of the difference. However, even allowing for the benchmark movement, it is obvious that some settlement occurred in the north toe area, and the elevation of the depth of thaw lowered a corresponding amount. The natural ground surface slopes very gradually from north to south, and surface water flows to the northern edge of the runway embankment and to a culvert located west of the west site. The existence of surface water (Fig. 39b) along the north toe is the most likely reason for the thaw and settlement there. The elevations recorded for 1977 (except for the north toe area) showed only a small amount of settlement, and at least part of this settlement may be attributable to regrading operations performed annually on the gravel surface.

In the west test section, little distinguishable settlement occurred during the two years except in the north toe area. The surface elevations recorded for 1978 are shown in Figure 42 along with the 1976 elevations in the north toe area and depth of thaw elevations for 1976 and 1978. As at the east site, the existence of surface water is the most likely cause of the subsidence in the north toe area.

Cone penetrometer measurements performed at the east and west test sites are shown in Table 19. Permafrost existed at a depth of 46 cm for points 39.1 and 56.9 m south of the centerline of the east end test

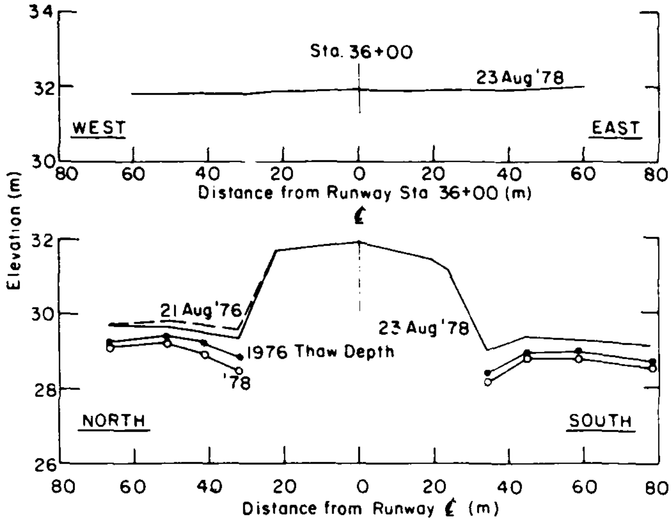


Figure 42. Surface elevations at the west site, Old Man Airfield. The upper drawing is the centerline profile; the lower drawing is the cross section at runway station 36+00.

Table 19. Cone penetrometer measurements at Old Man Airfield (2 September 1977).

Dist. from centerline (m)	Soil strength (psi) 0	15	30	46 cm
		Eastern Site		
60.3N	0	100	40	80
50.7N	0	40	30	80
31.7N	0	80	20	20
29.2N (Toe)	0	140	100	140
32.1S (Toe)	20	60	70	120
39.1S	0	60	70	pf*
48.4S	0	0	40	50
56.9S	10	150	160	pf
Average:	4	79	66	82
		Western Site		
67.2N	30	50	80	pf
51.6N	10	30	40	pf
41.5N	0	40	60	60
32.1N (Toe)	0	30	80	water
33.9S (Toe)		Too much gravel		
44.6S	30	60	180	160
58.5S	30	55	150	160
75.9S	0	10	50	50
Average:	14	39	91	108

* Permafrost.

Table 20. Probe observations at Old Man Airfield.

Dist. from centerline (m)	Depth to permafrost (m) 21 Aug. 1976	2 Sept. 1977	23 Aug. 1978
		Eastern Site	
60.3N	0.71+0.03 H_2O	0.51	0.45
50.7N	0.50+0.06 H_2O	0.48	0.32
31.7N	0.61+0.03 H_2O	0.66	0.65
29.2N (Toe)	0.82	0.94	0.98
32.1S (Toe)	0.61	0.72	0.75
39.1S	0.34	0.39	0.44
48.4S	0.36	0.51	0.45
56.9S	0.32	0.42	0.37
		Western Site	
67.2N	0.40+0.10 H_2O	0.47	0.52
51.6N	0.38	0.41	0.42
41.5N	0.42+0.02 H_2O	0.50	0.58
32.1N (Toe)	0.79+0.05 H_2O	0.89	0.89
33.9S (Toe)	0.70	0.77	0.80
44.6S	0.46	0.49	0.54
58.5S (Edge disturbed area)	0.41	0.52	0.45
75.9S	0.51	0.58	0.53

Table 21. Radiation measurements at Old Man Airfield (2 September 1977).

Location	Radiation (Btu/ft^2-hr) Incident	Reflected	Albedo
Runway	100	27	0.27
Disturbed (stripped)	100	12	0.12
Undisturbed	100	15	0.15

section and points 51.6 and 67.2 m north of the centerline of the west test section. In general, penetrometer readings on the south side increased with depth but on the north side tended to be somewhat erratic because of the wet conditions there. Both test sections showed lower penetrometer readings than at sites south of this area.

Yearly measurements of thaw depth adjacent to the runway test sections are given in Table 20. The depths did not vary significantly from year to year and were generally less than at sites south of Old Man. This difference was expected, since the southern test sites receive more incident radiation than the northern test sites. Incident and reflected radiation measurements for the west end of the runway are listed in Table 21. As expected, the disturbed areas showed the lowest reflected radiation values and the runway surface showed the highest.

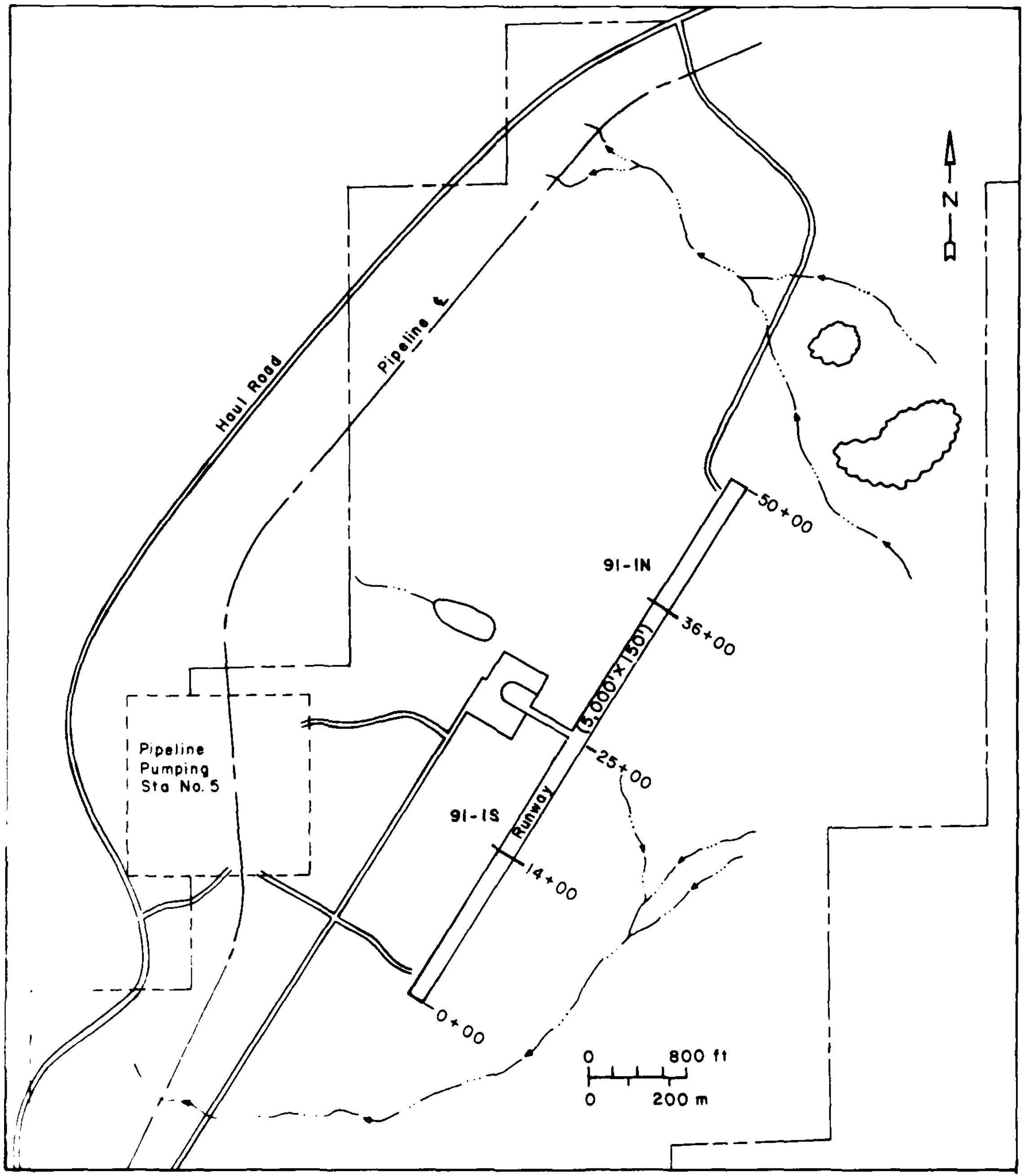


Figure 43. Prospect Airfield test site location.

Prospect Airfield

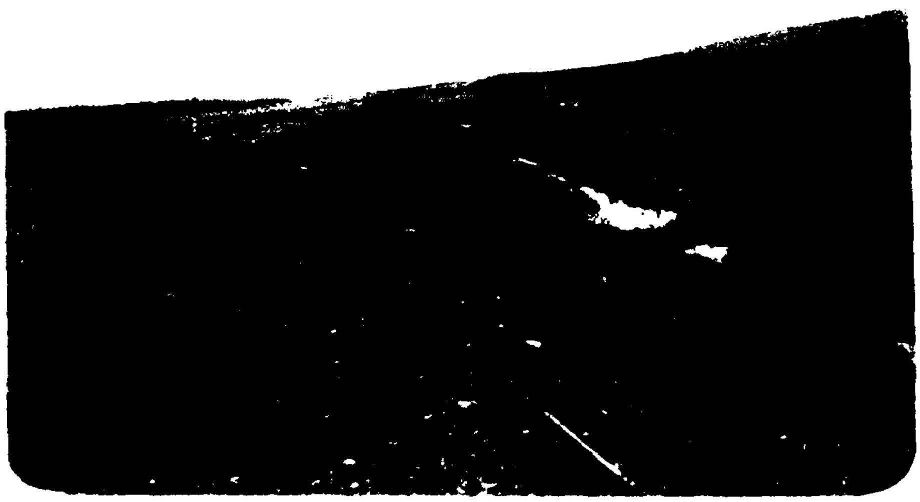
Figure 43 shows the location of Prospect Airfield. It is approximately 32 km north of the Arctic Circle and is situated in a continuous permafrost region. The airfield was constructed and temporarily used for flying in equipment for the trans-Alaska pipeline. Two sections were studied (Fig. 44).

a. North site, looking north along the east side from the cross section of the site.

b. North site, looking north along the west side from the cross section of the site.

Figure 44. Prospect Airfield north and south sites.

c. South site, looking north along the west side from the cross section of the site. Note the minor amount of water in this ditch, though some erosion and sloughing of the shoulder has occurred.



d. South site, looking north along the east side from the cross section of the site. Note the isolated pools of water in the ditch and the relatively little sloughing or erosion of the shoulder.

Figure 44 (cont'd). Prospect Airfield north and south sites.

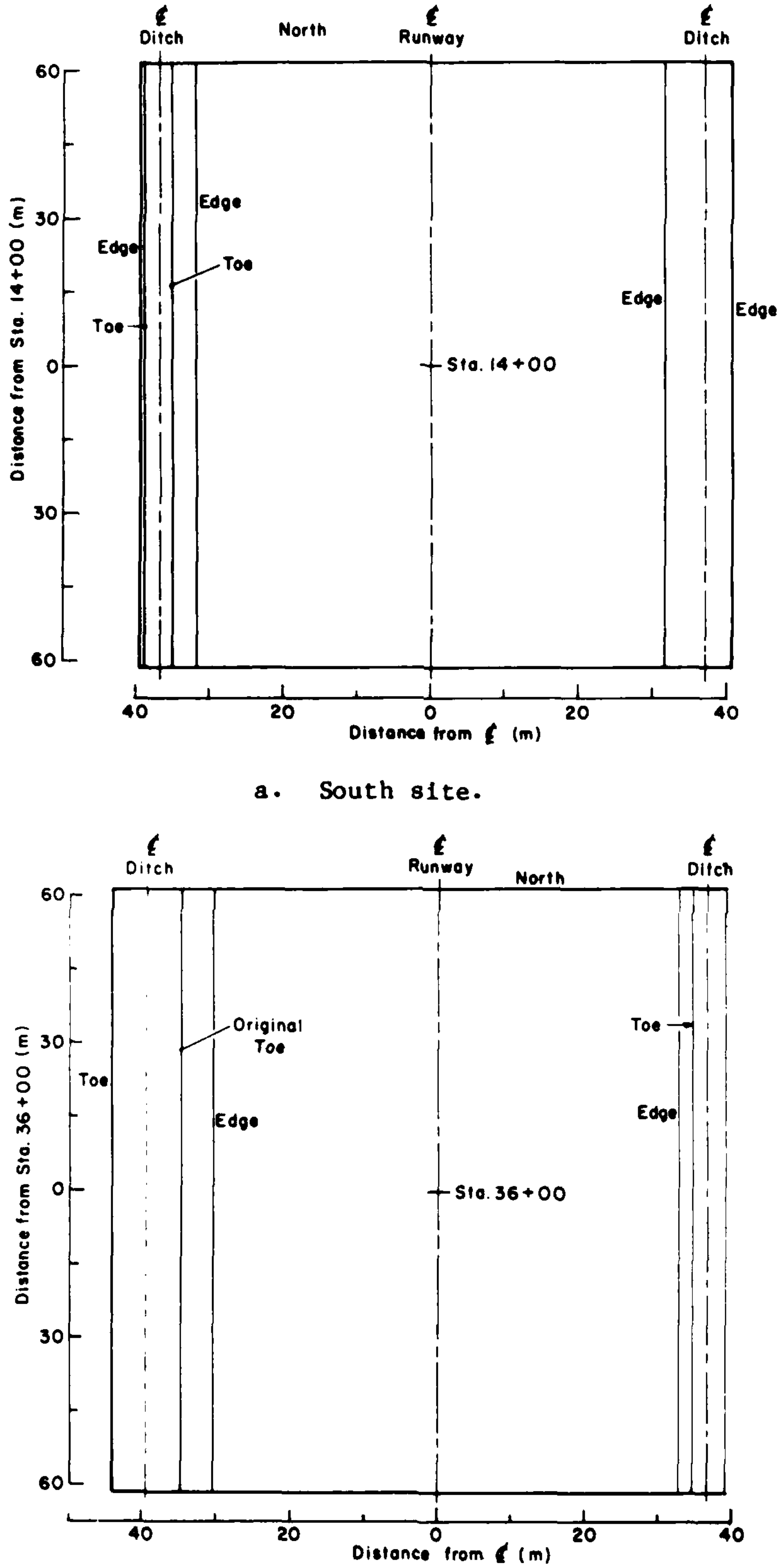
e. Large depression in the runway shoulder on the east side about 50 m south of the south site caused by an uncorrected drainage problem.

Figure 44 (cont'd).

For the northern section the temporary benchmark is the top of a stake on the west side of the north end of the runway. It was established during the fall 1976 survey, and an elevation of 30.48 m was assigned since the actual elevation was not determined. For the southern section a temporary benchmark was established during the fall 1976 survey. It is the top of a yellow stake on the west side of the runway. An exact elevation was not known, so an elevation of 30.48 m was assigned to the TBM for use in producing the cross section and profiles.

The nearest NGS benchmark, stamped W152 1974, was established in July 1975. It is located 1.13 km north along the Haul Road from the junction of the entrance road at Pump Station 5, at the junction of a road leading northwest, 32 m northwest of the centerline of the road, about 76 cm lower than the highway. It is a disk on the top of a copper-coated rod driven to a depth of 2.4 m; the disk projects 18 cm above the ground.

Shown in Figure 45 are plan views of the north and south test sections indicating the centerlines of the runway and ditches, the runway edges,



a. South site.

b. North site.

Figure 45. Plan views of the Prospect Airfield test sites.

and the toes of slopes. A new toe was recorded during September 1977 on the northern test site 34.16 m west of the runway centerline, 1.0 m east of the original toe of 1976. (This new location is not shown on the plan view in Figure 45.)

Level surveys were conducted on 20 August 1976, 1 September 1977 and 23 August 1978. At the northern site, observations showed no settlement of the runway embankment itself, although some minor settlement of the shoulders did occur and the west bank of the west ditch subsided up to about 0.3 m during the two-year period. Both settlements were most likely the result of yearly deepening of thaw induced by surface water drainage along the ditches. Figure 46 shows the surface elevations recorded in 1978 for both the cross section at station 36+00 and the centerline profile 60 m on either side of that station. Also shown on the west side of the cross section are the 1976 elevations of the ditch bank and westward and the 1976 and 1978 depth of thaw points in that area.

At the southern site the same lack of settlement was observed, again with the exception that the shoulders showed some settlement due to influence of ditch drainage. The settlement of the west shoulder was greater than the east, reaching about 0.3 m at the west edge, probably as a result

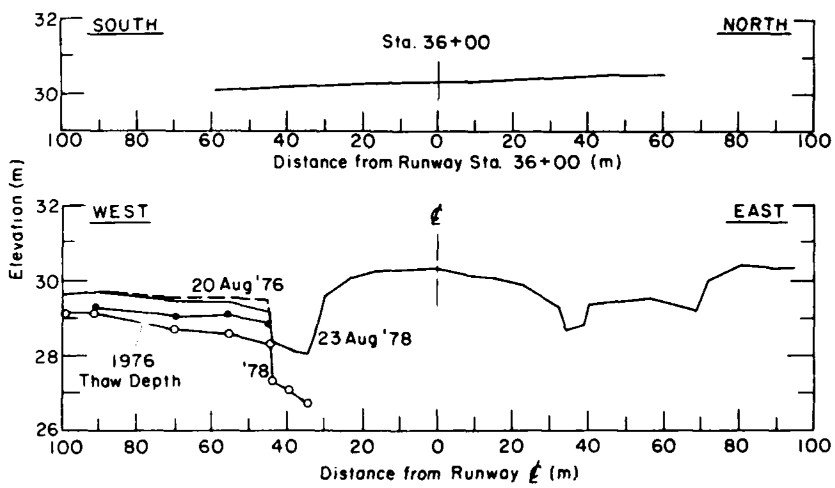


Figure 46. Surface elevations, north site, Prospect Airfield. The upper graph shows the elevations on the centerline profile, 23 August 1978; the lower graph shows the elevations on the cross section, runway station 36+00.

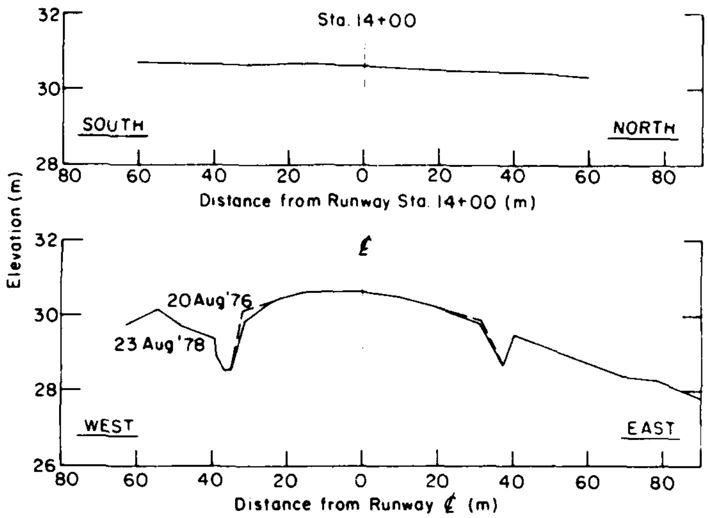


Figure 47. Surface elevations, south site, Prospect Airfield. The upper graph shows the elevations on the centerline profile, 23 August 1978; the lower graph shows the elevations on the cross section, runway station 14+00.

Table 22. Cone penetrometer measurements at Prospect Airfield (1 September 1977).

Dist. from centerline (m)	Soil strength (psi) 0	15	30	46 cm
			Northern Site	
99.0W	0	40	50	180
90.8W (Clearing limit)*	0	20	40	50
87.0E (Clearing limit)	0	20	40	100
95.1E (East stake)	0	20	40	pf†
Average:	0	25	43	110
			Southern Site	
63.3W	0	30	90	90
87.8E	10	60	90	180
91.3E	0	20	50	100
Average:	3	37	77	123

*Soil strength between 69.8W and 81.3E on the northern section and 54.6W and 77.6E on the southern section could not be measured because the surface was disturbed.

†permafrost.

of greater flow in the west ditch. Figure 47 shows the elevations recorded in 1978 for the centerline profile and the cross section at station 14+00. Also shown on the cross section are 1976 elevations at the shoulders.

Table 22 gives the cone penetrometer measurements taken on 1 September 1977 for both test sections. Average penetrometer readings for the two sites combined at the surface and 15, 30 and 46 cm depths are 1.7, 31, 60 and 116 psi, respectively. These values are lower than the penetrometer

Table 23. Probe observations at Prospect Airfield.

Dist. from centerline (m)	Depth to Permafrost (m)		
	20 Aug. 1976	1 Sept. 1977	23 Aug. 1978
		Northern Site	
99.0W	0.58	0.69	0.55
90.8W (Edge of clearing)	0.47	0.57	0.55
69.8W	0.48	0.66	0.74
55.8W	0.50	0.70	0.76
45.0W (Top)	0.58	0.85	0.87
44.6W (Toe)	0.90	1.17	1.06
39.9W (Ditch side)	1.20	>1.19	1.03
35.2W (Toe)	1.45+.13 H_2O	>1.19	1.35
34.3E (Toe)	1.13	>1.19	>1.50
39.0E (Ditch toe)	1.57	>1.19	---
40.6E (Top)	1.42	>1.19	---
57.2E	1.70	Rocky	---
69.2E	1.52	>1.19	---
71.9E	0.57	0.60	---
81.3E	0.41	0.44	---
86.9E (Edge of clearing)	0.60	0.64	---
95.0E	0.38	0.43	---
		Southern Site	
63.3W	0.58	0.61	0.49
54.6W	0.59	0.60	0.57
48.4W	0.48	0.67	0.72
39.4W (Ditch edge)	1.79	>1.19	>2.00
39.0W (Toe)	1.45	>1.19	>2.00
36.8W (Ditch centerline)	1.30+0.12 H_2O	>1.19	>2.00
35.2W (Toe)	1.20	>1.19	---
37.3E (Ditch centerline)	0.70+0.02 H_2O	Gravel	0.65
40.5E (Ditch edge)	0.52	Gravel	---
54.1E	2.00	Gravel	---
70.3E	1.37	>1.19	1.31
77.6E	0.52	0.55	0.63
87.8E	0.46	0.79	0.63
91.3E	0.47	0.62	0.49

readings from most test sites south of Prospect. The penetrometer measurements in the north test section were somewhat lower than those observed at the south test area for the same depths, but the small number of tests performed makes comparison difficult.

The probe measurements (Table 23) show that the thaw was deepest at the side slope toes and the ditches. In general, thaw beneath the ditches deepened during the two-year period, but there are not sufficient data for a more definitive statement. No radiation measurements were recorded for this test site during the two years. The mean annual air temperatures for 1977 and 1978 were -4.8 and -3.7°C, respectively.

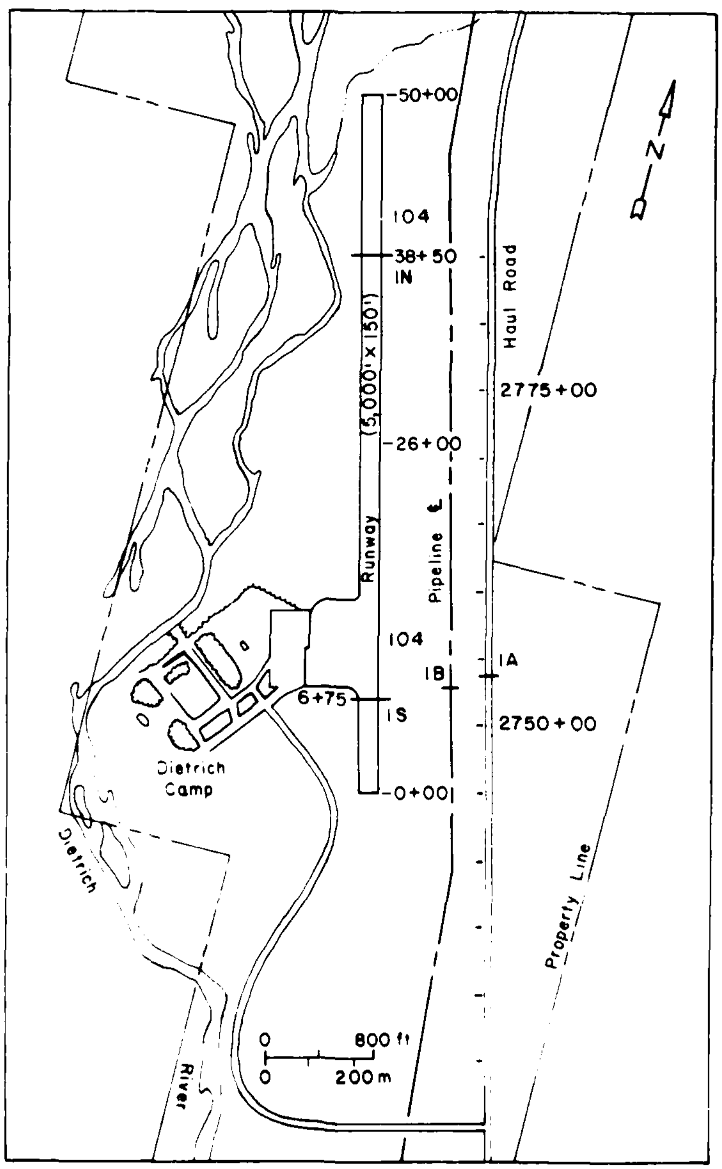


Figure 48. Dietrich Airfield test site location.

Dietrich Airfield

Figure 48 shows Dietrich Airfield, the pipeline route and the Haul Road. The airfield was built primarily for flying in equipment during the construction of the trans-Alaska pipeline. Two sections were studied (Fig. 49).

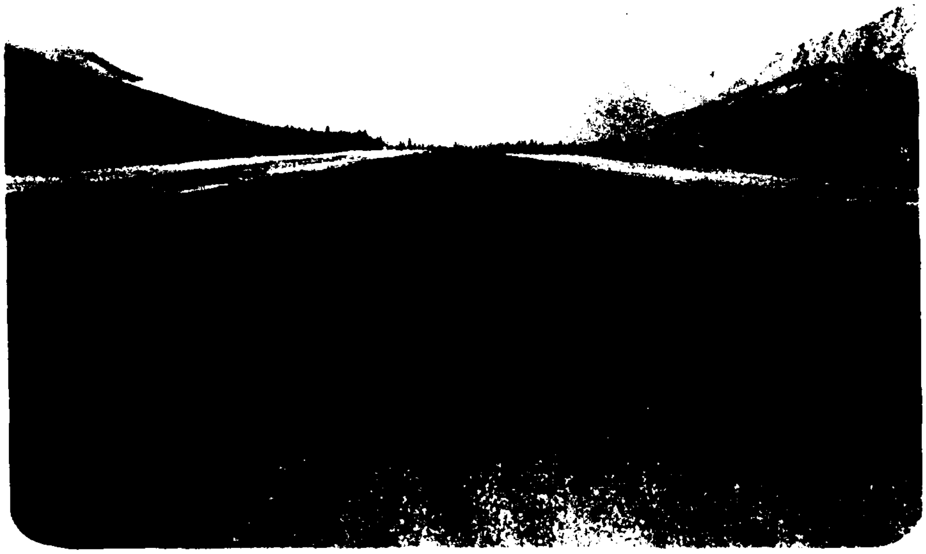
The temporary benchmark for the north test section was established during the fall 1976 survey. It is the top of a stake on the east side of the runway located near the sixth light from the north end of the runway. An elevation of 30.48 m was assigned since the actual elevation was not known.

The benchmark for the south test section was NGS benchmark T156 1974, established in July 1975. It is located 97.93 km south along the Haul Road from the junction of the entrance road at Pump Station 4, 80.5 m south of a 91-cm metal culvert, 20.3 m west of the centerline of the highway, 75.4 m east of the centerline of the pipeline pad, and about 1.83 m lower than the highway; it is a disk on top of a copper-coated rod driven to a depth of 2.44 m. The disk projects 0.3 m above the ground. An elevation of 30.48 m was assigned since the actual elevation was not known.

a. North site, looking north along the east shoulder of the runway. Note the shoulder cracks.

Figure 49. Dietrich Airfield north and south sites.

b. North site, looking north along the west shoulder. Note the shoulder cracking and the service road adjacent to the runway.



c. North site, looking north along the runway centerline from the southernmost point of the centerline profile.

Figure 49 (cont'd). Dietrich Airfield north and south sites.

d. South site, looking east from the runway centerline along the cross section. Note the pipeline (about 170 m from the runway edge) and the Haul Road visible beneath the pipe (about 250 m from the runway edge).

e. South site, looking west from the runway centerline along the cross section.

Figure 49 (cont'd).

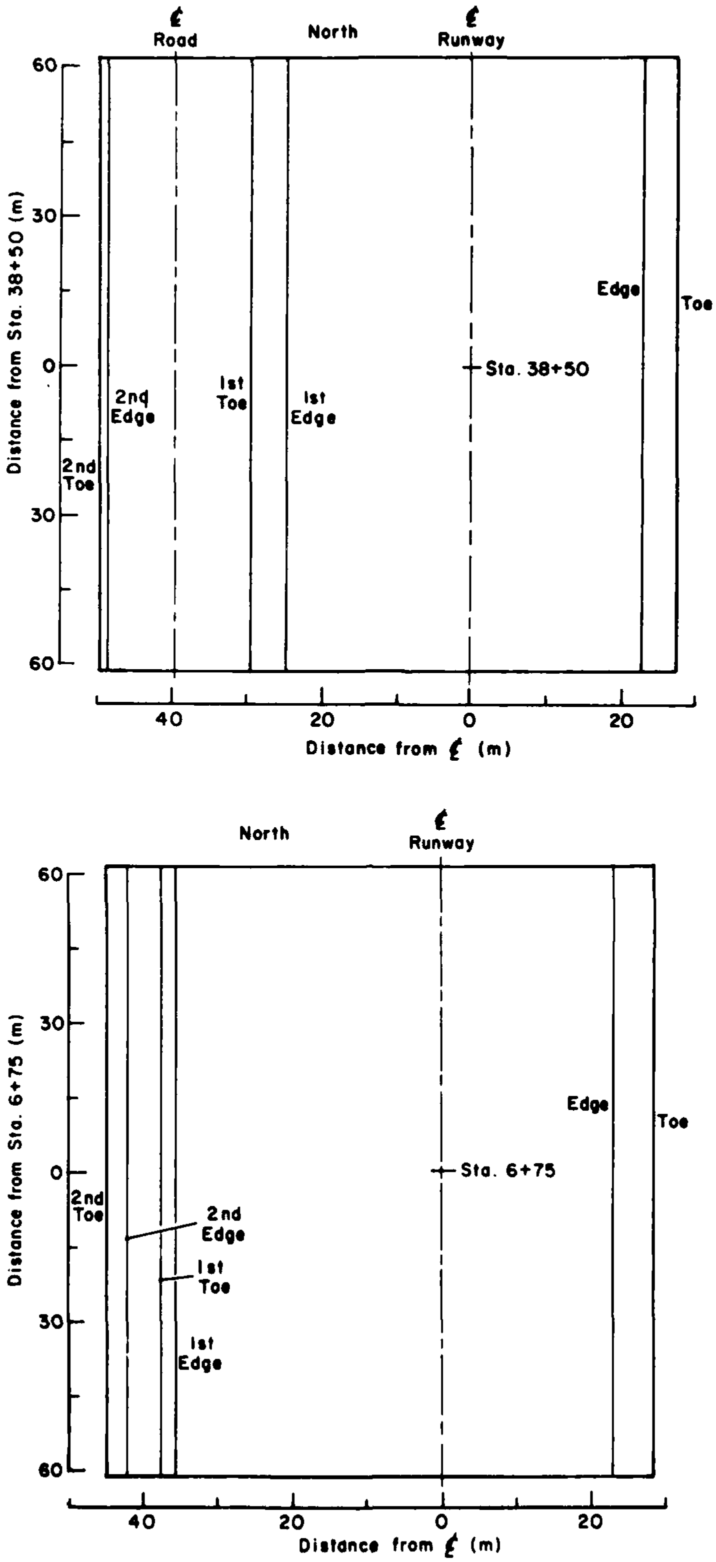


Figure 50. Plan views of the test sites at Dietrich Airfield.

Figure 50 shows the plan views of the two test sections. Surface elevations were measured on 19 August 1976, 31 August 1977 and 24 August 1978. Figure 51 shows the 1978 surface elevations for both the centerline profile and the cross section at the north site, along with the 1976 elevations for the centerline profile and the same year's data on the cross section for east and west runway toe and shoulder areas; 1976 and 1978 depth of thaw data are also shown on the cross section plot. As shown in Figure 51, settlement along the runway centerline was not uniform, varying from about 0.15 m, 40 m south of the cross section line to none at the line to about 0.25 m, 40 m north of the cross section. The settlement between 1977 and 1978 was only about half of that between 1976 and 1977. Along the cross section the only settlement occurred at the east and west toes and shoulders. Settlement in the west toe was relatively uniform over the two-year period, while at the east toe almost all occurred in the first year. The lowering of the depth of thaw followed the same pattern at these two areas.

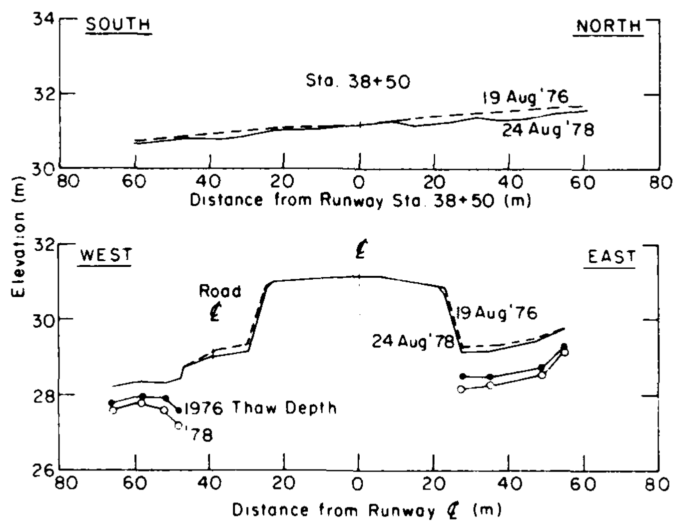


Figure 51. Surface elevations, north site, Dietrich Airfield. The upper graph shows the elevations on the centerline profile; the lower graph shows the elevation on the cross section, station 38+50.

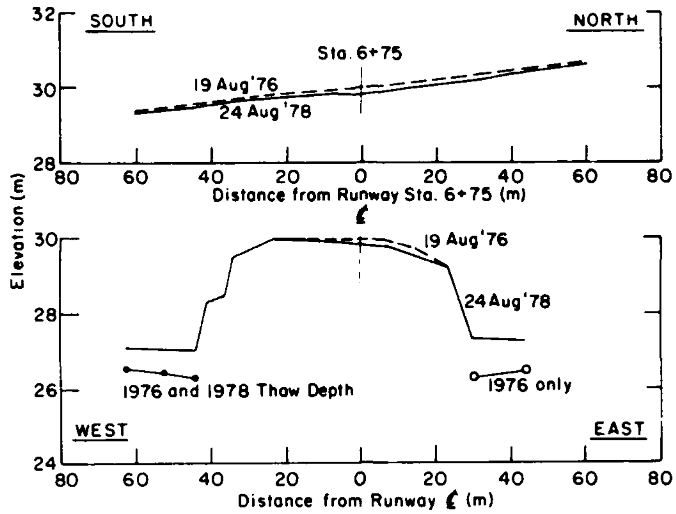


Figure 52. Surface elevations, south site, Dietrich Airfield. The upper graph shows the centerline profile; the lower graph shows the elevations on the cross section, station 6+75.

Figure 52 presents the same data for the south site. Settlement along the runway centerline was essentially uniform over the two-year period and did not produce the undulations noted for the north site. Along the cross section no settlement was recorded at either toe or shoulder areas, but some lowering of the runway embankment surface occurred over the two-year period, increasing in magnitude from west to east. The uniform nature of this settlement over the two years and the lack of shoulder toe settlement suggest that the change may have resulted from periodic regrading of the surface.

Cone penetrometer readings (Table 24) were generally higher than at the other airfields. Probe measurements were also conducted annually to determine the depth of thaw (Table 25). The north site showed an increase in thaw depth each year and, coupled with the settlement occurring where the probes were made, resulted in lowering the elevation of permafrost up to a maximum of about 0.4 m. Based on the limited data available, the south site thaw depths showed no change. Radiation measurements were obtained in late August 1977 (Table 26); they showed no difference in the amount of radiation absorbed and reflected by the runway, gravel and undisturbed areas. Incident radiation values were the highest of all the test sites.

Table 24. Cone penetrometer measurements at Dietrich Airfield (31 August 1977).

Dist. from centerline (m)	Soil strength (psi)			
	0	15	30	46 cm
		Northern Site		
54.8E	0	130	140	80
44.0E (Edge of clearing)	0	40	80	130
35.1E	20	90	120	120
27.6E (Toe)	30	50	140	130
47.9W (Toe)	0	130	90	140
52.0W	10	80	80	110
58.2W (Edge of clearing)	0	20	20	90
66.2W	0	55	110	---
Average:	20	74	98	114
		Southern Site		
60.0E	10	80	80	80
42.2E	10	30	60	90
23.3E (Toe)		Too many rocks		
43.8W (Toe)	120	130	100	111
52.4W	0	50	50	100
62.8W	10	30	95	160
Average:	30	64	77	108

Table 25. Probe observations at Dietrich Airfield.

Dist. from centerline (m)	Depth of permafrost (m)		
	19 Aug. 1976	31 Aug. 1977	24 Aug 1978
		Northern Site	
54.8E	0.53	0.58	0.59
44.0E (Edge of clearing)	0.85	0.84	0.90
35.1E	0.83+0.02 H_2O	0.98	0.96
27.6E (Toe	0.86	0.97	1.00
47.9W (Toe)	0.92	0.99	1.20
52.0W	0.46	0.62	0.70
58.2W (Edge of clearing)	0.39	0.47	0.58
66.2W	0.49	0.50	0.60
		Southern Site	
60.0E	---	0.43	---
43.2E	0.83+0.04 H_2O	0.99+0.08 H_2O	---
28.3E (Toe)	1.13 flowing H_2O	>1.12	---
43.8W (Toe)	0.72	0.67	0.74
52.4W	0.72	0.62	0.65
62.8W	0.59	0.55	0.55

Table 26. Radiation measurements at the northern site at Dietrich Airfield (31 August 1977).

	Radiation (Btu/ft^2-hr)		
Location	Incident	Reflected	Albedo
Runway	135	20	0.15
Gravel	135	20	0.15
Undisturbed	135	20	0.15

Galbraith Lake Airfield

Figure 53 shows the location of the Galbraith Lake Airfield. This airfield was also built for transporting equipment during the construction of the trans-Alaska pipeline. Two sections were studied; the south site is shown in Figure 54. No photographs are available for the north site.

Temporary benchmarks were established in the fall 1976 survey. At both test sites the tops of yellow stakes on the east side of the runway were set as benchmarks. An elevation of 30.48 m was assigned to both. Two new benchmarks were established on 25 August 1978 because the original

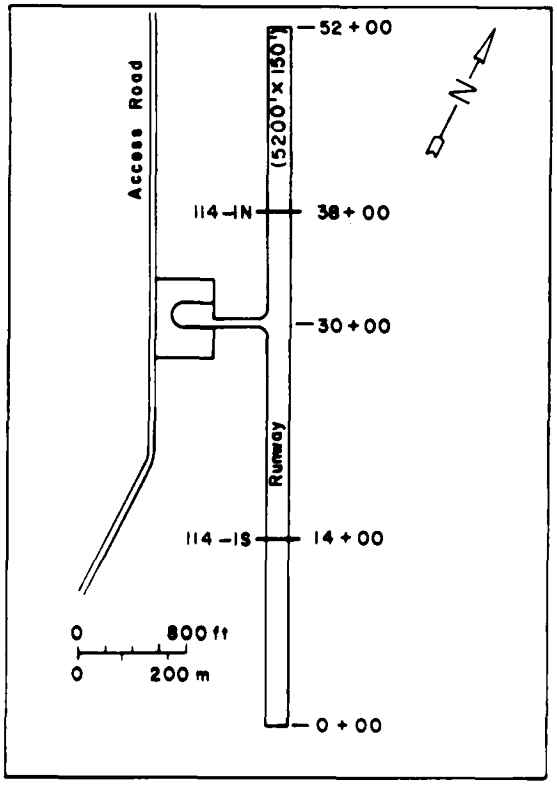
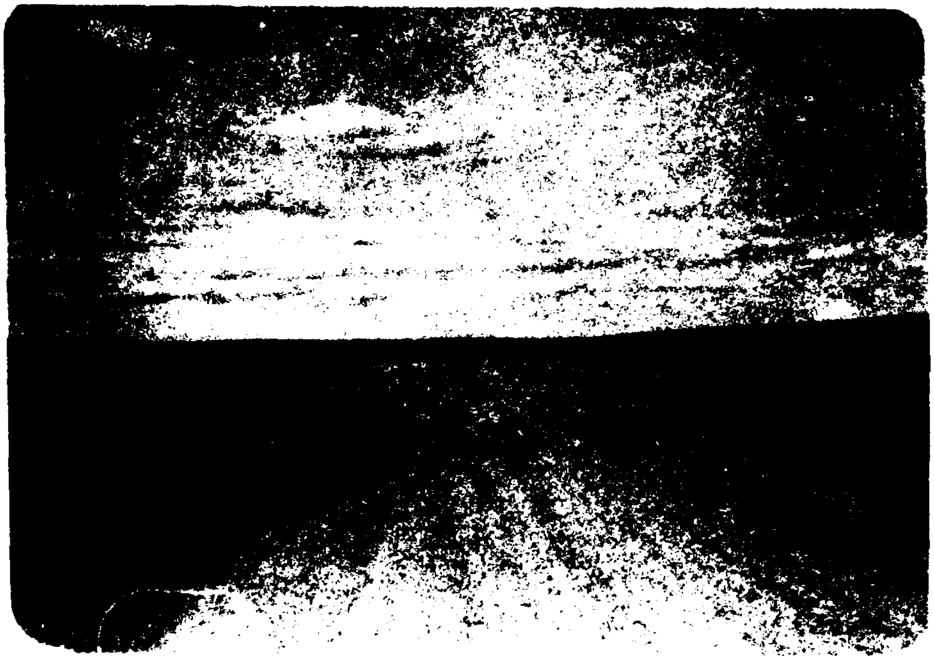


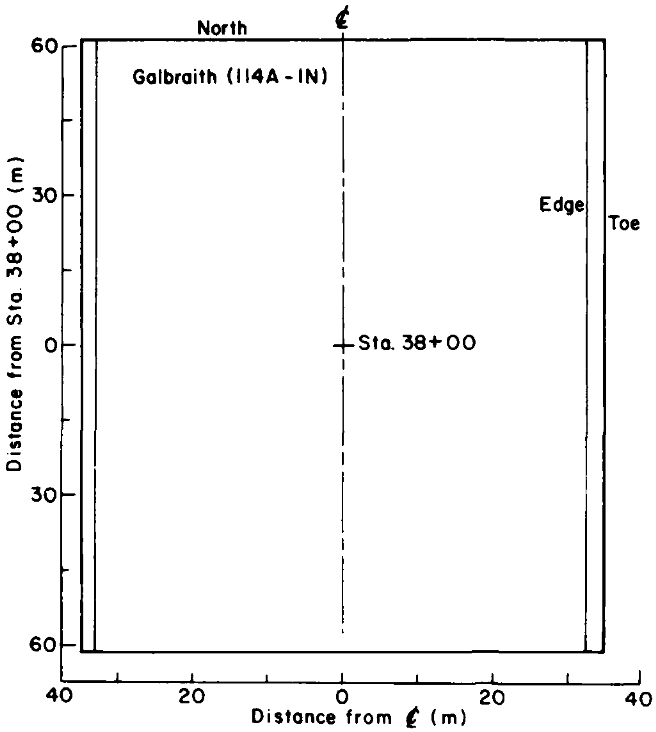
Figure 53. Galbraith Lake Airfield location.



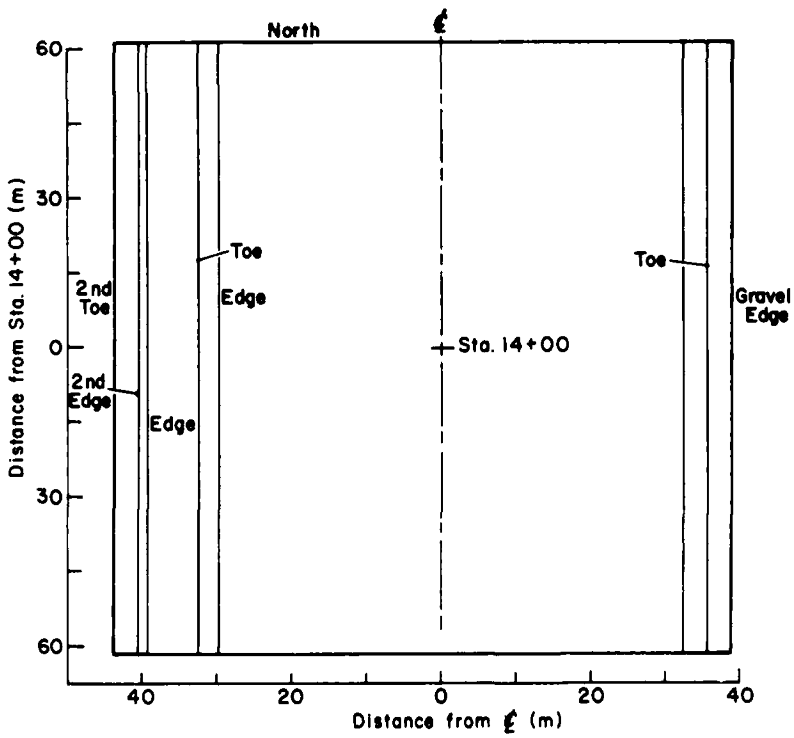
a. Looking north from the centerline of the runway.

b. Looking east from the centerline of the runway along the cross section.

Figure 54. South site, Galbraith Lake Airfield, 29 August 1977.



a. North site.



b. South site.

Figure 55. Plan views of the Galbraith Lake Airfield test sites.

benchmarks had moved. For the north test site the top of a bolt in the decking of the glide slope indicator, about 106.7 m north of the cross section and on the east side of the runway, was established as the benchmark. For the south test site the top of a bolt in the decking of the glide slope indicator on the west side of the runway was used. An elevation of 30.48 m was assigned to both.

The nearest NGS benchmark, stamped A 150 1974, was established in July 1975. It is located 8.4 km north along the Haul Road from the junction of the entrance road at Pump Station 4, 965.6 m south of the junction of the entrance road to Galbraith Lake Camp, 80.47 m southeast of the most southerly of the three metal pipe culverts, 32.3 m northeast of the centerline of the highway, and about 0.46 m lower than the highway; it is a disk on the top of a copper-coated rod driven to a depth of 3.7 m. The disk projects 0.18 m above the ground.

Figure 55 shows plan views of the test sections, indicating the runway centerline and the edges and toes of slopes. Level surveys were conducted on 18 August 1976, 29 August 1977 and 25 August 1978.

Figures 56 and 57 show the 1976 centerline profile and cross section elevations for the two sites along with 1976 and 1978 depths of thaw determined by probings. Although some settlement seemed to be indicated by the 1978 data, it was so uniform across the sections and along the profiles that movement of the TBMs undoubtedly is the reason for any difference. Depth of thaw adjacent to the runway (Table 27) lowered an average of about 13 cm over the two-year period at both sites; this is not a significant

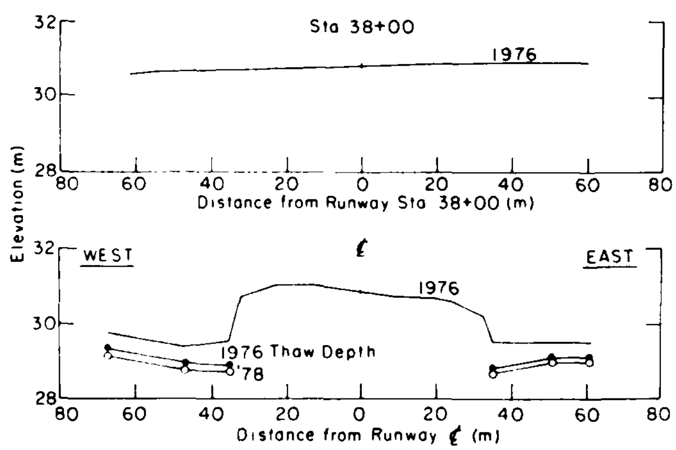


Figure 56. Surface elevations, north site, Galbraith Lake Airfield. The upper graph shows the elevations on the centerline; the lower graph shows the elevations on the cross section, station 38+00.

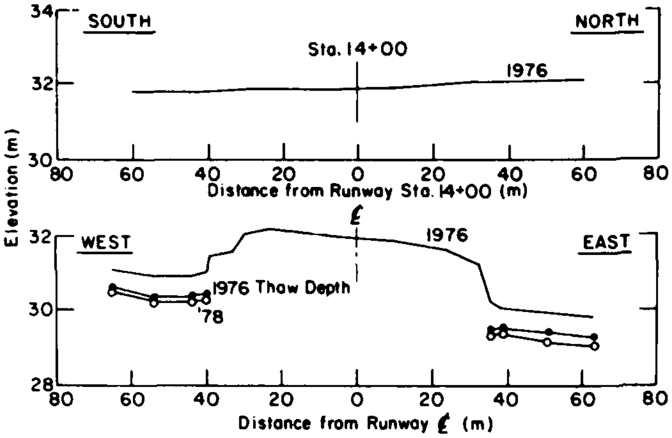


Figure 57. Surface elevations, south site, Galbraith Lake Airfield. The upper graph shows the elevations on the centerline; the lower graph shows the elevations on the cross section, station 14+00.

Table 27. Probe observations at Galbraith Airfield.

Dist. from centerline (m)	Depth to permafrost (m) 18 Aug 1976	29 Aug 1977	25 Aug 1978
		Northern Site	
68.0W	0.41	0.51	0.57
46.7W	0.43	0.47+0.03 H_2O	0.58
34.9W (Toe)	0.65	0.79	0.79
33.9E (Toe)	0.68	0.80	0.84
50.0E	0.38	0.43	0.46
60.6E	0.37	0.43	0.45
		Southern Site	
65.5W	0.47	0.51	0.53
53.9W	0.55	0.62+0.05 H_2O	0.66
43.8W	0.51	0.57	0.59
40.3W	0.62	0.69	0.70
34.6E (Toe)	0.74	--	0.85
39.0E (Edge of gravel)	0.52	0.62+0.03 H_2O	0.63
50.8E	0.52	0.67	0.76
63.4E	0.56	0.67	0.74

amount and did not result in any noticeable settlement in toe or shoulder areas at either site.

Cone penetrometer measurements were recorded at both the north and the south test sections (Table 28). Both test sections showed a gradual increase in soil strength with depth. No radiation measurements were recorded at this test site.

Table 28. Cone penetrometer measurements at Galbraith Airfield (29 August 1977).

Dist. from centerline (m)	Soil strength (psi) 0	15	30	46 cm
		Northern Site		
68.0W	0	90	90	80
46.7W	0	80	50	40
34.9W	0	80	120	150
33.9W	-	--	--	--
50.0E	0	50	65	--
60.6E	0	25	50	--
Average:	0	65	75	90
		Southern Site		
65.5W	0	80	100	95
53.9W (flowing water)	0	80	95	90
43.8W	0	70	95	95
39.0E (Edge of gravel)	0	80	80	130
50.8E	0	90	90	110
63.4E	10	90	140	--
Average:	0	82	100	104

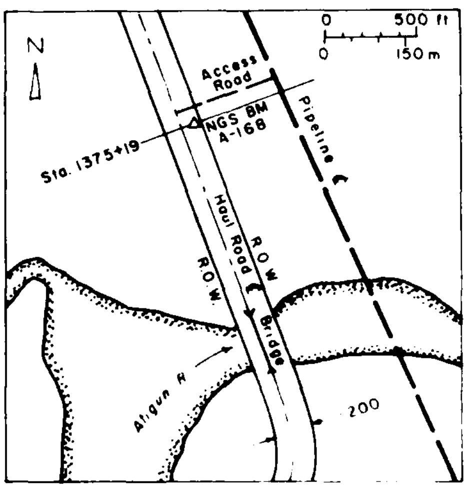
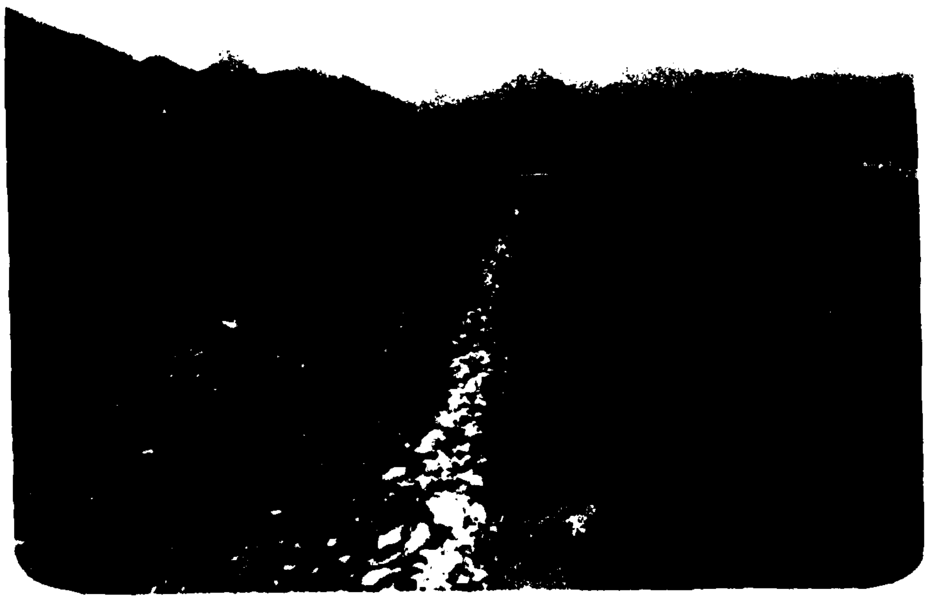


Figure 58. Access Road 114-APL-3 test site location.

Access Road 114-APL-3

Figure 58 is a map of this site, which is at an access road between the Haul Road and the pipeline workpad about 3.2 km north of Pump Station 4 and just north of the Atigun River crossing. Both the access road and the pipeline pad were studied (Fig. 59).

a. Looking east along the centerline of the access road from the centerline of the Haul Road. Note the grading operations in progress, creating gravel berms at the edge of the roads.



b. Looking south along the east shoulder of the Haul Road toward the intersection with the access road.

Figure 59. Access Road 114-APL-3 site, 29 August 1977.

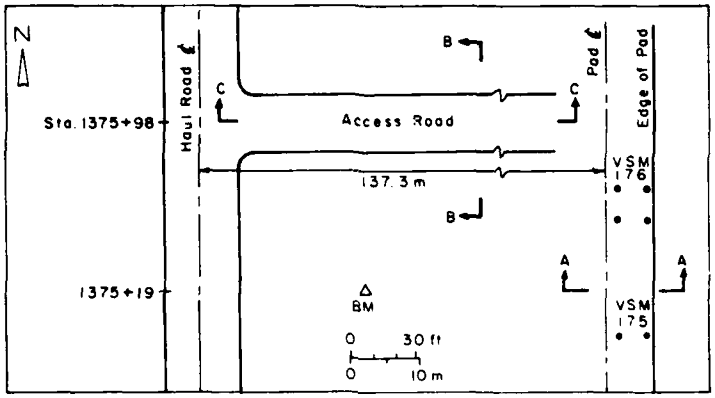


Figure 60. Plan view of the Access Road 114-APL-3 site.

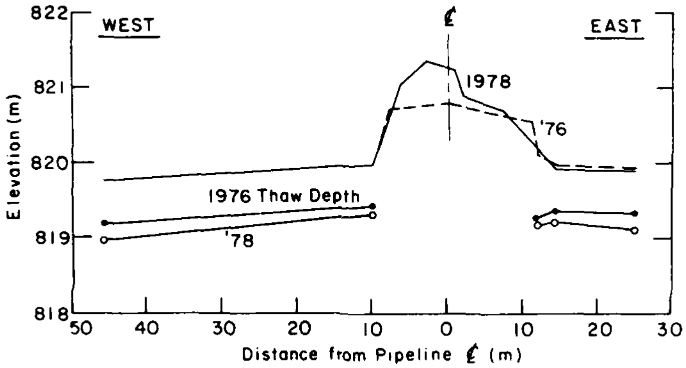


Figure 61. Surface elevations on cross section A-A, pipeline workpad, Access Road 114-APL-3.

The vertical control monument stamped A168 1975, set at an elevation of 818.03 m, was established by NGS in July 1975. It is 3.4 km north along the Haul Road from the junction of the entrance road at Pump Station 4, 321.9 m north of a bridge over the Atigun River, at the T junction of a graveled road (114-APL-3) leading east, 23.5 m east of the centerline of the Haul Road, and about 15 cm lower than the highway; it is a disk on the top of a copper-coated rod driven to a depth of 1.5 m. The disk projects 15 cm above the ground.

A plan view of the area is given in Figure 60. Level surveys were conducted on 18 August 1976, 29 August 1977 and 25 August 1978.

Figure 61 shows the 1978 surface elevations for section A-A across the pipeline pad at about midway between vertical support members (VSM) 175 and

Table 29. Probe observations at Access Road 114-APL-3.

Dist. from centerline (m)	Depth to permafrost (m) 18 Aug 1976	29 Aug 1977	25 Aug 1978
	Pipeline pad cross section (A-A)		
45.8E	0.61	0.72	0.78
10.0W (Toe)	0.43	0.65	0.67
12.0E (Toe)	0.90	0.95	0.98
14.2E	0.60	0.72	0.69
25.0E	0.60	0.74	0.76
Average	0.63	0.76	0.78
	Access Road cross section (B-B)		
24.8S	0.40	0.53	0.55
17.6S	0.55	0.64	0.63
7.4S (Toe)	0.59	0.81	1.00
6.1N (Toe)	0.59	0.77	0.90
20.4N	0.71	0.76	0.79
34.1N	0.50	0.60	0.67
Average	0.56	0.68	0.76

176, 24.8 m south of the access road centerline. Also shown are 1976 elevations from the west toe to 25.0 m east of the pad centerline and 1976 and 1978 depth of thaw points (Table 29). The reshaping of the pipeline pad occurred prior to the 1977 survey. The 1977 and 1978 elevations show only minor differences, and the only settlement observed was east of the pad, occurring between the 1976 and 1977 surveys. The depth of thaw adjacent to the pad increased an average of 15 cm in the two-year period, with most occurring in the first year.

Figure 62 shows 1976 and 1978 surface elevations on the access road cross section (section B-B) and centerline profile (section C-C). Also shown are depth of thaw points on the cross section for 1976 and 1978. The change in the elevations of the eastern half of the centerline profile occurred between the 1976 and 1977 surveys and resulted from the need to raise the road to meet the higher level of the pipeline pad (Fig. 61). The apparent settlement along the western half of the profile occurred after the 1977 survey and is attributable to work in progress at the time of that survey. The surface elevation changes shown in Figure 62 for the road embankment are a result of regrading work over the two-year period, while the settlement shown from the north toe outward most likely resulted from

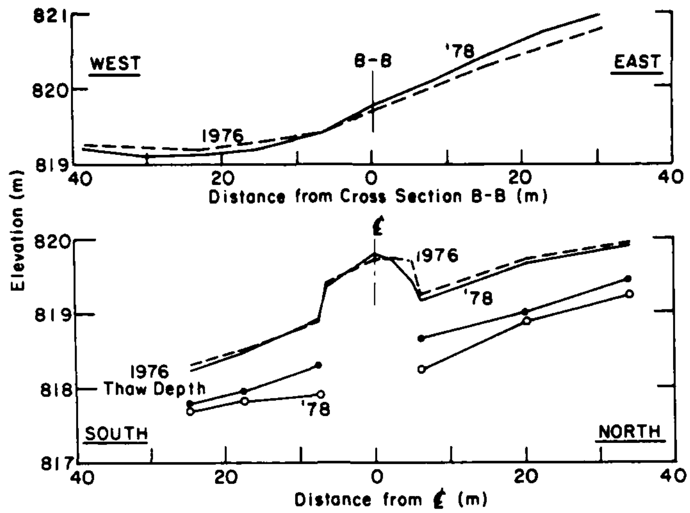


Figure 62. Surface elevations, Access Road 114-APL-3. The upper graph shows the centerline profile (Section C-C); the lower graph shows the elevations on cross section B-B.

Table 30. Cone penetrometer measurements at Access Road 114-APL-3 (30 August 1977).

Dist. from Pipeline Pad centerline (m)	Soil strength (psi) 0	15	30	46 cm
		Pipeline pad cross section (A-A)		
45.8W	0	130	170	180
10.0W (Toe)	0	120	160	120
12.0E (Toe)	20	130	240	>300
14.2E	10	120	280	>300
25.0E	10	100	160	220
		Access Road cross section (B-B)		
24.8S	30	150	140	30
17.6S	0	80	95	140
6.1N (Toe)	0	140	140	--
20.4N	10	180	180	100
34.1N	0	110	70	30
Average	8	126	164	>158

the increase in the depth of thaw in that area. The increase in the depth of thaw along this cross section (Table 29) averaged 20 cm but was greatest under the embankment toes.

Cone penetrometer measurements were made at the site on 30 August 1977 (Table 30). The average values were the highest of all the test sites presented in this report, with the maximum recorded readings at 12.0 and 14.2 m east of the pipeline pad centerline.

Insulated Pipeline Workpad

Figure 63 shows the location of this test site. It is an above-ground pipeline workpad (Fig. 64) containing an estimated 10-cm layer of extruded polystyrene insulation about 30-38 cm below the surface to slow or prevent thaw of the subgrade. The depth of fill placed above natural ground surface, including insulation, appears to be shallow, averaging only about 0.5 m. An Alyeska Pipeline Service Company benchmark of unknown elevation was used for vertical control at this site, with an elevation of 30.48 m assigned to it. The benchmark is located on the cross section 19 m west of the workpad centerline. Figure 65 is a plan view of the site.

Level surveys along with thaw depth probings (Table 31) were performed at the site on 18 August 1976, 28 August 1977 and 25 August 1978. Shown in Figure 66 are 1976 and 1978 surface elevations on the workpad cross section and on the longitudinal profile 6.1 m east of the workpad centerline. In addition, 1976 and 1978 thaw depths are shown on the cross section plot. The exaggerated scale of Figure 66 (1 unit vertical vs 5 horizontal) gives

Table 31. Probe observations at the insulated pipeline workpad.

Dist. from centerline (m)	Depth to permafrost (m) 18 Aug 1976	28 Aug 1977	25 Aug 1978
45.0W	0.25	0.30	0.29
31.3W	0.55	0.58	0.60
16.5W	0.43	0.48	0.50
13.4W (Toe)	0.63	0.72	0.74
12.7W (Edge)	0.89	--	---
11.9E (Edge)	0.94	--	---
12.8E (Toe)	0.57	0.56	0.65
22.1E	0.44	0.41	0.44
30.8E	0.44	0.44	0.42

Figure 63. Insulated pipeline workpad test site location.

a. Looking north along the centerline of the workpad. Note the wheel ruts in the gravel surface.

b. Looking north on the east side of the workpad.

Figure 64. Insulated pipeline workpad site, 28 August 1977.

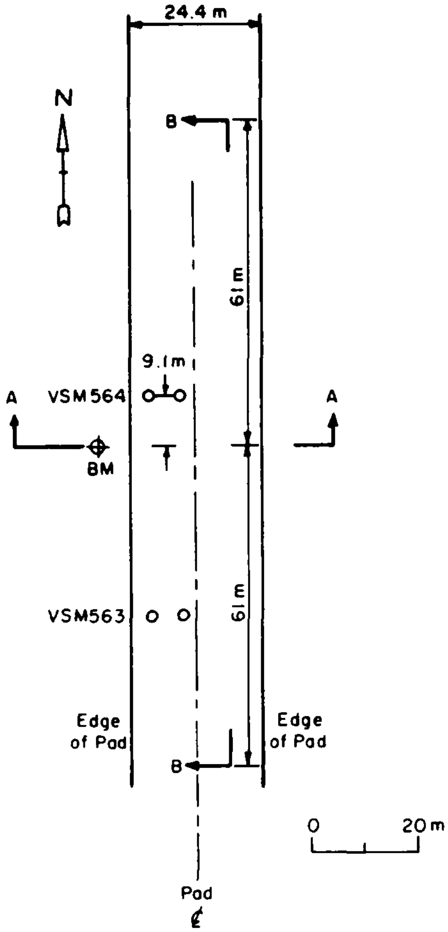


Figure 65. Plan view of the insulated workpad site.

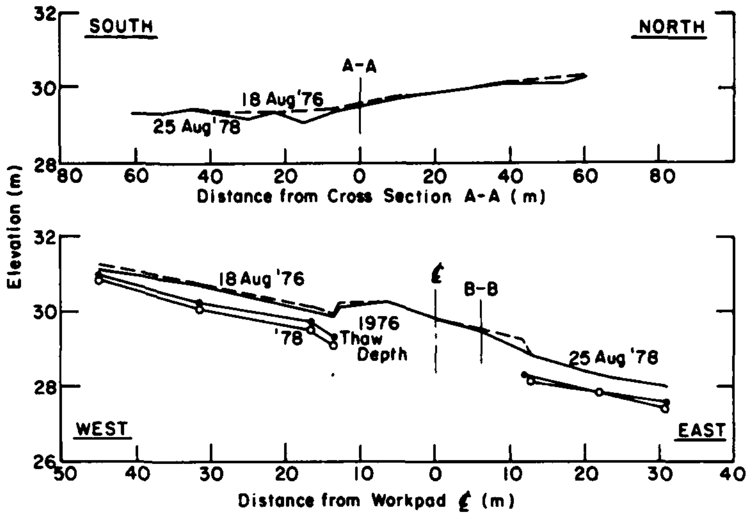


Figure 66. Surface elevations of the insulated workpad site. The upper graph shows the profile 6.1 m east of the workpad centerline (section B-B); the lower graph shows the elevations on cross section A-A.

the effect of a moderate slope, whereas the true slope is only 4% from west to east and less than 2% north to south. Figure 66 shows a small, almost uniform, settlement from the west toe outward on the cross section, averaging about 8 cm, with a corresponding lowering of the thaw depth, all of which occurred in the first year. Thaw depths on the east side showed only minor fluctuations over the two-year period. Some settlement or sloughing of the workpad shoulders appears to have occurred, also in the first year, but most of this apparent movement probably resulted from surface grading operations. In Figure 66, some differential settlement is indicated along the profile 6.1 m east of the workpad centerline, reaching a maximum of about 30 cm about 1 m south of the cross section (A-A). About half of this differential settlement occurred during the first year. It is unlikely,

Table 32. Cone penetrometer measurements at the insulated pipeline workpad (28 August 1977).

Dist. from centerline (m)	Soil strength (psi) 0	15	30	46 cm
45.0W	0	80	--	--
31.3W	0	50	100	140
16.5W	20	60	140	--
13.4W (Toe)	0	30	140	160
12.8E (Toe)	0	30	170	--
22.1E	0	60	80	--
30.8E	0	80	130	--
Average	3	56	127	150

though possible, that this settlement resulted from surface grading operations, but since practically all of it occurred some distance from the cross section, there are no data to permit a conclusion.

No radiation measurements were made at this site. Cone penetration measurements were taken at the site on 28 August 1977 (Table 32).

Access Road-133-APL-1

Figure 67 shows the location of this site, an access road connecting the Haul Road and the pipeline (Fig. 68). The road fill is gravel averaging about 1 m in height. Figure 69 is a plan view of the test site showing the location of the centerline profile (A-A) and the cross section (B-B).

The NGS benchmark stamped W146 1974 is located 15.7 km north along the Haul Road from the junction of the north entrance road at Franklin Bluffs Camp, 80.5 m south of the junction of a graveled road leading east, 37.8 m east of the centerline of the highway, and about 1.07 m lower than the highway; it is a disk on the top of a copper-coated rod driven to a depth of 2.44 m and projecting 21 cm above the ground surface. Its elevation was established as 78.71 m.

Surface elevations were measured and probings for depth of thaw (Table 33) performed on 17 August 1976, 27 August 1977 and 26 August 1978. Cone penetrometer tests and radiation measurements were not performed at this site.

Figure 70 shows the surface elevations along the centerline profile (A-A) and the cross section (B-B) and thaw depths beneath the cross section

Figure 67. Access Road 133-APL-1 test site location.

Figure 68. Access Road 133-APL-1 site, 17 August 1976. Looking north from the Haul Road toward the intersection with the access road.

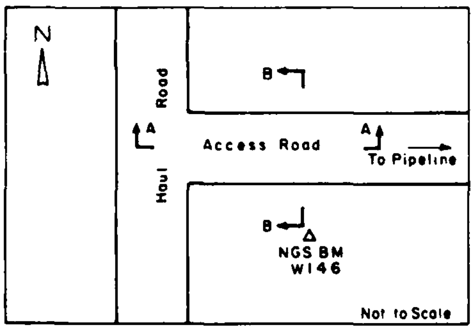


Figure 69. Access Road and Haul Road plan view, site 133-APL-1.

Table 33. Probe observations at Access Road 133-APL-1, Section B-B.

Dist. from Access Road centerline (m)	Depth to permafrost (m) 17 Aug. 1976	27 Aug. 1977	26 Aug. 1978
58.1S	0.65	0.69	0.69
35.8S	0.60	0.64	0.63
10.1S (Toe)	0.73	0.76	0.81
8.6N (Toe)	0.64	0.69	0.76
19.5N	0.53	0.62	0.53
30.1N	0.57	0.62	0.58

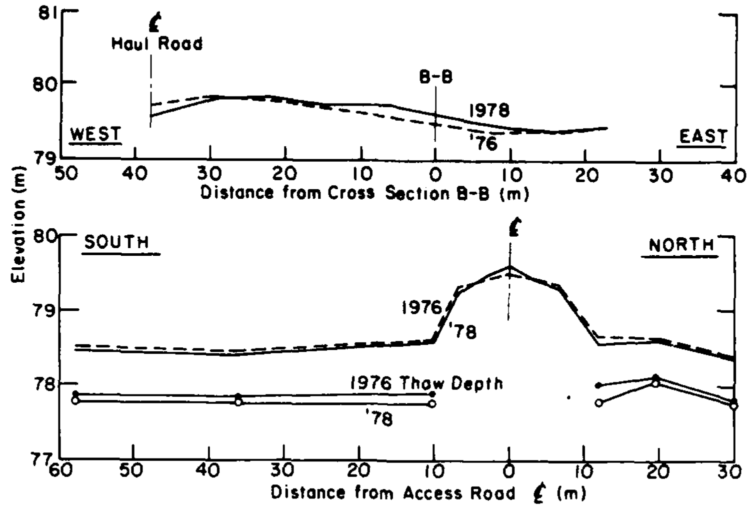


Figure 70. Surface elevations, Access Road 133-APL-1. The upper graph shows the elevations on the centerline profile (A-A); the lower graph shows the elevations on cross section B-B.

for 1976 and 1978. A small, uniform amount of settlement, averaging perhaps 3 or 4 cm, occurred from the south road toe outward, with a corresponding lowering of the thaw depth varying from about 8 cm farthest out to about 12 cm at the toe. Settlement at the north toe was about 10 cm, diminishing to a negligible amount 18 m north of the toe. The thaw depth at the north toe lowered about 20 cm, and this rapidly decreased with distance from the toe. Essentially all settlement and lowering of the thaw depth occurred in the first year. Variations in elevation across the embankment and along the centerline profile from 1976 to 1978 are the result of grading operations during the two-year period.

DISCUSSION

The results of this three-year environmental engineering investigation of roads, pipeline workpads and airfield test sites initiated in the spring of 1976 have contributed to determining under which conditions and at what rate thaw penetrates into the underlying permafrost and conversely the rise of the permafrost table into the active base layer.

Thaw penetration depths measured adjacent to the test sites in the summer of 1977 were generally slightly greater for all subarctic test sites than those measured in 1976. This trend is primarily attributed to the

higher air thawing indexes during 1977 at the test sites south of Atigun Pass (i.e. the division between the arctic climatic zone to the north and the subarctic zone to the south).

Thaw penetration measured in 1978 was generally greater than the 1977 thawing season beneath most test sites, even though the thawing index was greater in 1977 than in 1978. Because the thaw next to the test sites in the undisturbed areas is less than the thaw in the original soils beneath these construction systems, continued settlement has occurred along the embankments. According to the annual observations, most thaw depth variations in the undisturbed areas were related to the air thawing indexes, the amount of incident radiation, and the water content of the soil. Depths of thaw beneath the gravel surface of all test sites and the air thawing indexes decreased from south to north. The magnitude of surface modifications of thaw regimes adjacent to the road under the various climatic conditions was established. Experience with road and airfield construction in these unique, cold-dominated regions has shown that modifying the surface with almost any type of road system results in thermal regime changes in the underlying soil (Mackay 1970).

Within the first year after completion of Haul Road, airfield and pipeline workpad construction, the permafrost table beneath most of the side slopes rose. After a few years most of these gravel surfaces subsided because of consolidation of the mostly thawed, previously existing active layer. Road-grading operations have resulted in the toe moving outward slightly and the edge of the shoulder moving inward toward the centerline. Because of greater thawing beneath the side slopes, they have subsided more than the trafficked portion of the embankment. Thaw subsidence has caused the trafficked surface to become narrower as the side slopes become wider and flatter. Since the rate of permafrost degradation and resulting thaw settlement has decreased annually, the thermal regime at most sites appears to be stabilizing.

RECOMMENDATIONS

Recommendations for improved design criteria specifications governing construction and restoration in a wide range of climatic and permafrost conditions in Alaska are as follows:

1) Vertical control monuments should be installed at the test sites where benchmarks have moved due to winter frost action. Annual comparisons of the cross sections and centerline profiles can then be accurately made.

2) Future level surveys should be performed to obtain additional data necessary to increase knowledge of construction systems under the different seasonal climatic regimes.

3) Grading should be done to remove any gravel berms remaining on the workpad, roadway and runway edges that would inhibit lateral runoff of water to roadside slopes and edges.

4) Runoff water that ponds on the tundra adjacent to the roadway, workpad and airfield embankment should be avoided.

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